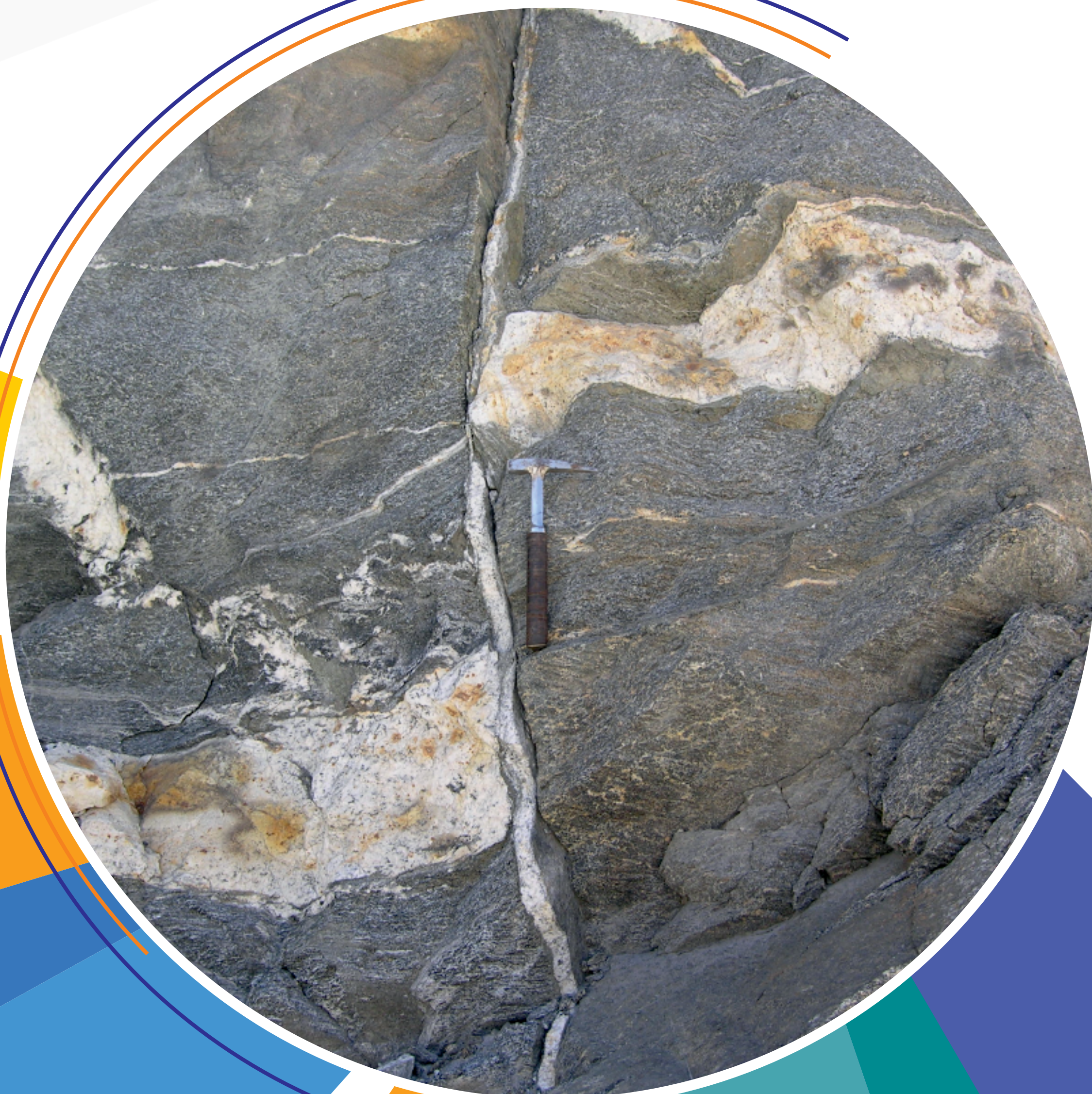
ANNUAL REPORT
2019-20



WADIA INSTITUTE OF HIMALAYAN GEOLOGY
DEHRADUN
(An Autonomous Institute of Dept. of Science & Technology, Govt. of India)

Cover Photo: Felsic veins within Karakoram Plutonic rocks showing evidence of normal faulting and propagation of younger veins along the fault plane.

(Courtesy: Shailendra Pundir and Dr. Vikas)

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WADIA INSTITUTE OF HIMALAYAN GEOLOGY

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RESEARCH ACTIVITIES

RESEARCH GROUPS

- Structure & Tectonics
- Igneous Petrology & Geochemistry
- Sedimentology
- Biostratigraphy
- Geophysics
- Geomorphology & Environmental Geology

THRUST AREA THEMES

- Geodynamic Evolution of the Himalaya and Adjoining Mountains
- Indian Monsoon-Tectonic Interaction and Exhumation of the Himalaya
- Earthquake Precursors Studies and Geo Hazard Evaluation
- Biodiversity - Environment Linkage
- Himalayan Glaciers: their role in Indian Monsoon variability and Hydrological changes in the Ganga Basin

UNITS ANCILLARY TO RESEARCH

- Research Planning & Co-ordination Cell
- Publication & Documentation
- Library
- Museum
- Drawing Section
- Photography Section
- Instrument Maintenance
- Sample Preparation Section

ADMINISTRATION

- Registrar's Office
- Finance & Accounts
- Establishment
- Stores & Purchase
- Works, Building & Maintenance
- Transport
- Guest House

EXECUTIVE SUMMARY

Wadia Institute of Himalayan Geology is mandated to carry out fundamental and applied research developing the hypothesis and evolutionary models of Himalaya and its peripheral regions. We adopt a multidisciplinary approach using geophysics, structural geology, petrology, sedimentology, biostratigraphy and glaciology. The field based observations are strongly supported by state of the art laboratories in geochemistry, isotopes, geochronology, and deep- and shallow- earth probing geophysical equipment. The outcomes, besides adding significantly to the knowledge base on surface and deep earth orogenic processes, provide geoscience support in understanding and mitigation of various hazards like landslides, earthquakes and floods in Himalaya. The institute's research activities, ending in the March 2020, had following thrusts areas themes (TAT):

TAT-1: Geodynamic Evolution of the Himalaya and Adjoining Mountains
TAT-2: Indian Monsoon-Tectonic Interaction and Exhumation of Himalaya
TAT-3: Earthquake Precursors Studies and Geo-hazard Evaluation
TAT-4: Biodiversity-Environment Linkages
TAT-5: Himalayan Glaciers: their Role in Indian Monsoon Variability and Hydrological Changes in the Ganga Basin.

The major contribution made by institute's scientists in the above stated TATs during the year 2019-20 is given below:

Geodynamic Evolution of Himalaya and Adjoining Mountains

- Geoelectric imaging has been carried out along the Nahan-Kaurik Chango region of Satluj Valley, northwest Himalaya. A 2D geo-electrical model has been obtained along the profile that shows an Intra crustal High conducting layer at a depth of 8-10 km. The study infers an increase in thicknesses of the crystalline rocks of the Jutogh Formation progressively toward the north. The thrust faults and other surface features have been identified and correlated with available geological information.
- The receiver function image, obtained beneath 10 broadband seismological stations in eastern Ladakh-Karakoram zone, reveals a prominent layer with positive velocity contrast discontinuity after the Moho at a depth of 96-120 km, which is interpreted as the "Hales Discontinuity".
- GPS observations show the overall surface shortening rate between the Sub and the Tethyan Himalaya across the heavily locked Nahan salient is 15.4 ± 1.2 mm/yr; which along the frontal arc movement is abysmally low (~1 mm/yr) compared to the Tethyan block (16.4±0.8 mm/yr). Moreover, periodic (3 to 4 months) crustal movements are also observed not only in the vertical component (20 ± 10 mm) but also in the Horizontal components (10 ± 2 mm) owing to both hydrology and tectonic factors.
- A surface wave tomography has been carried out across the NW Himalaya and Tibetan plateau that provides a view of Indian plate Moho dipping towards the north and the Eurasian plate dipping south and detected broad low-velocity strata in the middle and lower crust in the part of Karakoram Fault and Tibetan plateau region. A high-resolution ambient noise tomography imaged the Main Himalayan Thrust with a double ramp structure in the hypocentre zone of Mw 7.8 earthquake of 1905.
- Metamorphic modelling helped constrain the P-T conditions of migmatization of the Leo Pargil dome that indicates prograde (600 ± 25°C, and 6.0 ±0.2 Kbar), peak (750 ± 25°C, and 7.8 ±0.2 Kbar) and retrograde P-T (670 ± 25°C, and 4.7 ±0.2 Kbar conditions.
- U-Pb geochronology and εHf record three distinct periods of zircon growth in the migmatite (1050-950, 850-790, and 650-500 Ma) of Leo Pargil. The 1050-950 Ma zircon population supports provenance from magmatic units related to the assembly of Rodinia.
- Discordia lower intercept age of 15.6 ± 2.2 Ma indicating the timing of decompression melting during crustal extension process along the Southern Tibetan Detachment.
- Petrological study reveals that the Zildat Fault initiated as a normal fault but reactivated as a reverse fault with SW vergence, an example of inversion tectonics during collision.
- Carbonate veins of ophiolite sequence show that the fluids with high radiogenic $^{87}Sr/^{86}Sr$ values and enriched in elemental Sr penetrated into the Sr-poor peridotite to produce the carbonate veins, and this

suggests involvement of continental crust-derived fluids, sourced from the adjacent gneissic dome.

- Mafic enclaves within the Ladakh Batholith show positive ε Nd, indicating derivation from mantle source while negative ε Nd of granitoids from this magmatic arc indicates originating from Juvenile lower crust.
- The magmatic rocks of Chaur Granitoid Complex (CGC), Himachal Himalaya are studied to shed light on Tectono-magmatic evolution. The U-Pb (zircon) geochronology results for granitoid samples yield age between 766 and 1080 Ma, with a few younger phases and older inherited ages. The granitic gneiss of the Jutogh group also offer two prominent age spectra for $^{206}Pb/^{238}U$, with weighted mean of 861 ± 8.27/16.21 Ma (MSWD = 0.31, n = 10) and 932 ± 10.0/19.6 Ma (MSWD = 1.57, n = 8).
- It is envisaged that CGC was intruded during the Grenvillian orogeny in northern marginal part of the Indian plate. It is also visualised that unidentified microcontinents, which were present in the northern margin, collided with the Indian plate and the subduction process coincides with the onset of the Grenvillian orogeny during the Neoproterozoic.
- LA-ICPMS zircon U-Pb ages of Jaspa granite suggest that two principal stages of magmatism, which took place during ~570-493 Ma (Vendian - Ordovician) were responsible for the generation of the Jaspa granite.
- The tectonothermal evolution of crystalline rocks of Mandi area, Himachal Himalaya show prograde clockwise P-T path, inferred from the outer crystalline rocks in NW Himalaya. This indicates an increase in both pressure and temperature during loading. The inferred P-T path is consistent with heating as a result of over thrusting of the hot overlying unit. Such P-T paths are consistent with the "critical taper" thermo-mechanical model rather than the widely accepted channel flow model.
- New Apatite Fission Track (AFT) and Zircon Fission Track (ZFT) data have been obtained along the distal transect cutting across Gianbul Dome. 09 Apatite Fission Track (AFT) ages across the Gianbul Dome range from 5.9±0.5 to 11.7±1.8 Ma. The exhumation rates have been obtained using the 1D AGE2EDOT thermal model by utilizing these ages that range from 0.28-0.51 mm/yr at a mean rate of 0.40 mm/yr since ~19 Ma. The AFT and ZFT ages do not show any correlation with respect to the elevation (Fig. 3). This suggests that these ages are independent of topographic effect, and variation in AFT ages across the dome is solely controlled by normal faulting.
- Geothermal springs of Garhwal Himalaya contain high $\delta^{13}C_{DIC}$ ratio (-3.4 ‰ to + 9.1‰ $_{VPDB}$) with bicarbonate (HCO_3^-) as major anion followed by sulfate, chloride, nitrate, and fluoride, and calcium is the major cation followed by magnesium, sodium, and potassium. The elevated concentration of Cl^- and Ca^{+2} in these spring waters suggests their deeper origin.

Indian Monsoon-Tectonic Interaction and Exhumation of Himalaya

- The Gangetic Foreland is a consequence of continent-continent collision and formation of the Himalayan thrust and fold belt. The sedimentary architecture analysis from various stratigraphic successions together with optically stimulated luminescence dating provided insights on interaction of peripheral bulge tectonics and climate over the past ~100 kyr. The results implied that the duration of 8054 ka was a period of forebulge uplift when gravelly fans prograded basin ward. Below the fan sediments lies a peripheral bulge unconformity marked by regionally significant pedogenic horizon, termed as peripheral bulge unconformity.
- A study on river systems of Himalaya, for the first time, for evaluating discharge during periods of river aggradation and incision over late Quaternary, implies that net river incision in the upper Indus River during early Holocene, occurs in relatively wetter climatic conditions when river discharge use to be ~6.17 $10^{-7}ms^{-1}$, which is at least six times higher than that during the net river aggradation.
- Peat deposits from Ladakh, Uttarakhand and Himachal Himalaya were studied. The 1.23 m thick sediment section, recovered from a wetland at Gya, Ladakh, provided a vegetation and paleo-environmental record of the last ~2700 cal. yr BP, and suggested for warm and wet conditions in Ladakh from *ca.* 2646 to 1860 cal. yr BP. The data from from ~1860 to 1154 cal. yr BP suggested decreased temperature and prevalence of cold-dry climate. This study also captured signals of medieval warm period. The statistical correlations amongst the proxies exhibited that Indian Summer Monsoon (ISM) is controlled by solar variability even in the rain shadow zone of the Himalaya. Similar study from Uttarakhand produced climate record that correlates well with the global and regional climate and changes in civilizations during

the mid-Holocene and captured signals of globally established Dry and cold corresponding to Dark Age Cold Period, Medieval Climate Anomaly and Little Ice Age. Likewise, a peat deposit of Kinnaur, Himachal Himalaya and a meadow litho-section of Chakrata, Uttarakhand provided good climate and weathering record for the past 10 ka.

- Two tributary glacial valleys were investigated in the upper Kali Ganga valley, Tethyan Himalaya, for the study of the palaeo glacial reconstruction concluded glacier advances during the MIS-4/3, MIS-2, Younger Drayas and Mid Holocene. The overall pattern of glaciation across the valley suggests that the low temperature and changes in the precipitation brought by westerlies may be the major reason influencing the timing and the extent of the glaciation during the last glaciation.
- Tree ring-width chronologies covering last millennia of *Cedrus deodara* were developed from moisture stressed sites of Gangotri region, Garhwal Himalaya. Tree-growth climate analyses of these chronologies revealed significant positive relationship with winter and spring precipitation. Likewise a well dated *Betula utilis* cores collected from Dokriani glacier forefield developed ring-width chronology extending back to AD 1710 that revealed influence of summer temperature on growth of trees in the region.
- A high resolution oxygen isotopes record of speleothem from the Wah Shikar cave, Meghalaya, NE India produced record of summer monsoon for the last ~900 yrs. The record nicely captured Medieval Climate Anomaly (MCA) and the Current Warm Period (CWP) that strengthened the Indian summer monsoon (ISM) whereas multiple shifts occurred during the Little Ice Age (LIA).
- Geochemical results *[*HCO_3+SO_4 *vs Ca+Mg]* from the Indus River system show that *the alkalinity in these waters may be sourced from the Silicate weathering*. A part of such weathering could be routed through the H_2SO_4 and hence it does not consume any CO_2 from the atmosphere.
- Equivalent Black Carbon (EBC) measurement near Gangotri Glacier shows variation from 0.01μg/m^3 to 4.62μg/m^3 during 2019-20. The diurnal variation ranges from 0.1μg/m3 to 1.8μg/m^3. The monthly mean concentration of EBC varies from a minimum of 0.087±0.046 μg/m^3 in August to a maximum of 0.823 ± 0.711 μg/m^3 in May. These reported values are far below that what can be termed as pollution but can have significant impact on heat budget of glacial valley.
- The grain size and environmental magnetic parameters of Arabian Sea sediments obtained from International Ocean Discovery Program (IODP) Site U1457 provided 200 ka evolution record of Indus fan and sea level variations.

Earthquake precursor studies and Geo-Hazard evaluation

- Crustal structure, stress field evolution across NW Himalaya, have been investigated based on seismic and gravity data. The study suggests that long-wavelength gravity anomalies arise due to variations in Moho depth (35 to 80 km), which are caused by the flexed lithosphere of an effective elastic thickness of ~53 km. ***Coulomb** stress modeling and seismicity in the NW Himalaya suggests* that the upper part of the MHT plane is locked and accumulates more strain and only slips during a great earthquake as compared to the lower part, which creeps steadily beneath the Eurasian plate and slips aseismically producing micro-earthquakes during the interseismic period.
- Preliminary investigations of seismicity have been carried out in the Siang window of the Eastern Himalayan Syntaxis, and it shows that the upper 40 km of the crust is seismogenic. The broadband seismograph network of the Siang window recorded a strong earthquake (Mw~5.9) on April 23, 2019. The source mechanism suggests a thrust faulting mechanism. The strike of the inferred fault plane follows the trend of the Main Central Thrust near the Machuka region. The receiver function study suggests a variation of crustal thickness within the range ~40-47 km.
- Surin Mastgarh anticline (SMA), NW Himalayan front marks the active deformation without exhibiting emergent Himalayan Frontal Thrust (HFT). The study of deformed strath terraces along Chenab and Munavar Tawi rivers and abandonment shows a geologic shortening rate across the SMA as ~ 4-6 mm/year, with vertical uplift rate of ~2 mm/yr since 29 ka estimated.
- A study from Kota Dun reveals that the fan aggradation continued at least since 59 ka and terminated in the distal region of the fans due to uplift and formation of piggyback basin at ~11 ka.
- The Electrical Resistivity Tomography methods at a site in Kala-Amb trench excavation could delineate three active fault zones in the Quaternary sediments, which shows three distinct litho units in terms of resistivity variation.

- GPS data from the Ramnagar-Haldwani and Haridwar networks using GAMIT/GLOBK and ITRF-08 combination frame reference velocities show NE-wards plate movement, which is in agreement with the established rates of the regional plate motion.
- Landslide susceptibility (LS) mapping of Mussoori township and a 10 km swath along the Main Central Thrust was carried out. For the Bhagirathi valley, advanced machine learning (ML) techniques using information value analysis and support vector analysis have been used, whereas for the Goriganga valley and the Mussoorie township, bivariate statistical Yule Coefficient (YC) method was used. An initial observation about the association of spatial distribution of landslides and earthquakes in the MCT zone suggest that there is a higher concentration of landslides in the zone of higher seismicity.

Biodiversity-Environment Linkages

- The study of Paleogene and Neogene fossil investigations from Indo-Burma Range (IBR) for their paleoenvironmental, biostratigraphic and tectonic implications were continued. A synoptic review of the Eocene-Miocene fossil records and its paleo-environmental comparisons with coeval sediments of the NW Himalaya is documented to infer tectonic settings and shed light on the collision of the Indian and the Eurasian plates. The review implied a plausibility of progressive south-west withdrawal of the Tethys Sea in a stepwise manner due to the episodic tectonics in the NW Himalaya. However, in the IBR the progressive withdrawal of the Sea took place from east to west.
- Biostratigraphic and geochronological investigations in eastern Nagaland and Manipur, NE India, provide new constraints on the tectonic evolution of the western margin of the Burma microplate and emplacement of Naga Hill Ophiolite.
- A new hominoid specimen (WIF/A 1825) was recovered from Rashole in the Ramnagar region and it was attributed to *Sivapithecus*. The specimen was systematically described to provide a working catalog of all published ape specimens from Ramnagar. Further a series of statistical tests were performed comparing premolar and molar metric variation of the published Ramnagar fossils with the Potwar Plateau Chinji Formation material.

Himalayan Glaciers: their Role in Indian Monsoon Variability and Hydrological Changes in the Ganga Basin

- Monitoring of the glaciers in Doda and Suru River basins was carried out. The measurements made on the ablation-stake network suggest that the net balance of the Pensilungpa glacier was negative in 2018-2019. During the measurement periods 2018/19 the net ablation of the glacier was ~ (-) 4.6 x10^6 m^3 we, while the net accumulation of the glacier was ~ (+) 1.49 x10^6 m^3 we. However, the ablation and accumulation gradients of the glacier were ~ (-) 0.120 m/100 m and ~ (+) 0.135 m/100m respectively.
- The surface ablation Pensilungpa glacier is spatially variable, with a maximum value of 3 m in the ablation zone between 4900 and 4950 m a.s.l. that reduces to 0.2 m near the equilibrium line altitude. The thick debris cover at lower elevation is attributed as a reason behind reduced melting at lower elevations.
- The measurements on terminus retreat of Pensilungpa glacier suggests that from Little Ice Age to 1971 glacier retreated by ~2671 ±48 m at an average rate of 5.9 ±0.1 m a^{-1} and that between 1971 and 2017 it was ~260 ±24 m at an average rate of 5.65 ±0.6 m a^{-1}. However from 2015 to 2019 the glacier retreated ~27 ±11.5 m at a much faster rate of 6.7 ±3 m a^{-1}.

Other Research highlights

i) Magma transport through saucer sills in Waka prospect of Canterbury Basin

The sill complexes significantly contribute to the transport and storage of hot magma, and doming of overburden. This acts as plausible structural traps for hydrocarbon accumulations in sedimentary basin. The petroliferous Canterbury basin off New Zealand is a classic example, where saucer-shaped magmatic sills are emplaced within the Cretaceous to Eocene succession resulting into forced folds and hydrothermal vents above the sill terminations. We have captured this scenario by designing workflows and computing Sill Cube (SC) and Fluid Cube (FC) meta-attributes. The outcome has prominently brought out the structural architecture of sill complexes and fluxed-out magmatic fluids within the Cretaceous to Eocene strata in the Waka prospect of Canterbury Basin (Fig.1) [P. C. Kumar & K. Sain, 2020. Interpretation of magma transport through saucer sills in shallow sedimentary strata: An automated machine learning approach, *Tectonophysics, 789 (228541), 1-16.]*

ii) Submarine Buried Volcanic System in the Kora Field o Taranaki Basin

The Kora field in northern Taranaki basin off NZ is well known for hydrocarbon prospects within the

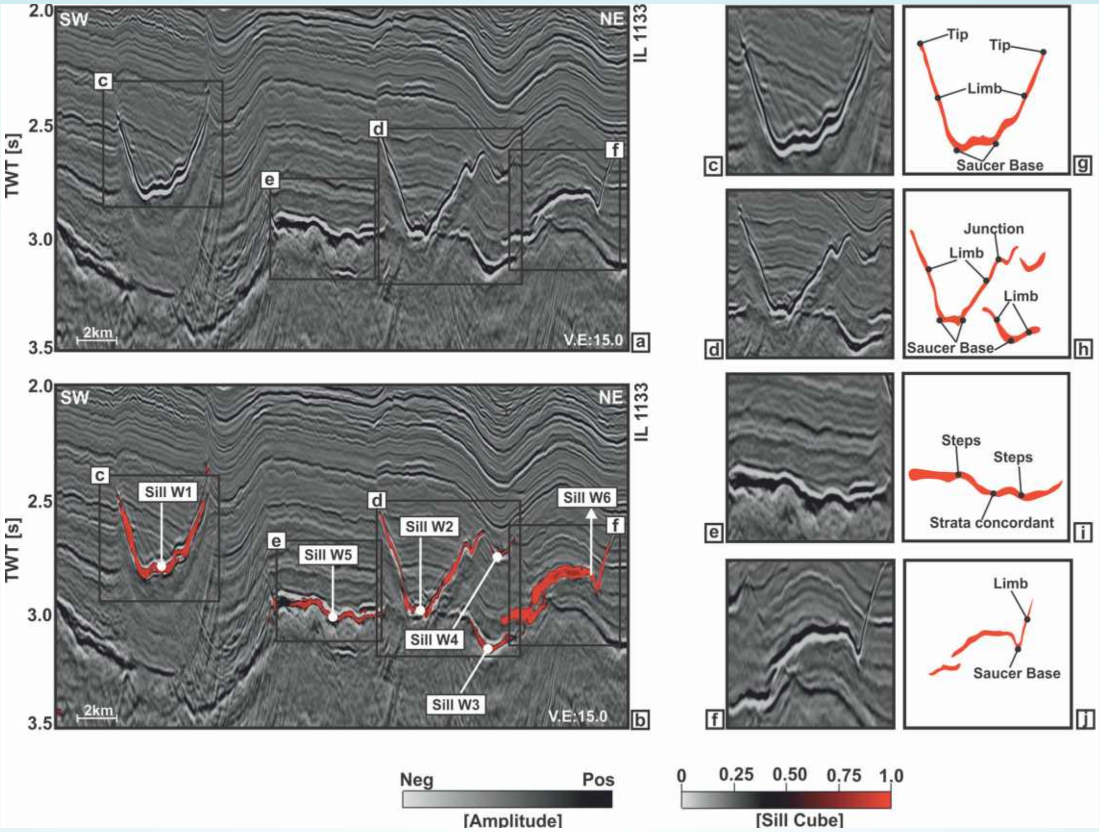

Fig. 1: (a) Interpreted section showing subsurface architecture of the Waka prospect Emplacement of sill complexes into the overlying sedimentary units resulted into forced folded strata; (b) Sill-cube (SC) meta-attribute co-rendered with interpreted seismic line; (c) & (d) Saucer shape sills depicting concave geometry with their limbs rising up and are intersected to other sill through junction; (e) Sills are connected through steps or bridges. (f) Sill showing saucer geometry with upward limbs.

volcanogenic deposits. The buried volcano and enclosing older sedimentary strata have been structurally modulated that has led to the structural and stratigraphic traps for hydrocarbon accumulation. The best possible image of complex geological system consisting of several structural elements such as the sill networks, dyke swarms, forced folds, drag folds, jacked up strata and pinch-outs has been captured in the host sedimentary successions along with delimitation of volcanic edifice through the computation of Intrusion Cube (IC) meta-attribute (Fig. 2). [P.C. Kumar, K. Sain and A. Mandal, 2019. Delineation of a buried volcanic system in Kora prospect off New Zealand using artificial neural networks and its implications. Journal of Applied Geophysics, 161, 56-75.]

iii) Fluid Leakage along Hard-linked Faults in Taranaki Basin

Increasing displacement and strain accumulation in normal faults can result into hard-linked structures that are preferred loci for fluid leakage. We have computed two different meta-attributes Thinned Fault Cube (TFC) and Fluid Cube (FC) that have apprehended detailed geometry of hard-linked fault zones and fluid-flow through these structures. The result shows the Miocene geological units that were structurally deformed to form several hard-linked fault or breached zones through which fluids have migrated into the younger strata (Fig. 3). The strikes of the faults are oriented into the NE direction with different geometries forming curved shapes (F1 & F2), sigmoid shapes (F3), Y shapes (F4) etc. [P.C. Kumar, K.O. Omosanya, T. Alves and K. Sain, 2019. A neural network approach elucidating fluid leakage along hard-linked normal faults. Journal of Marine and Petroleum Geology, 110, 518-538.]

iv) Lithology Prediction from downhole log data using ANN

The neural method has been employed for lithology prediction from downhole density, neutron porosity, gamma ray, resistivity and sonic logs, which were acquired at three sites (10A, 03A and 04A) in KG basin during the Expedition-01 of Indian National Gas

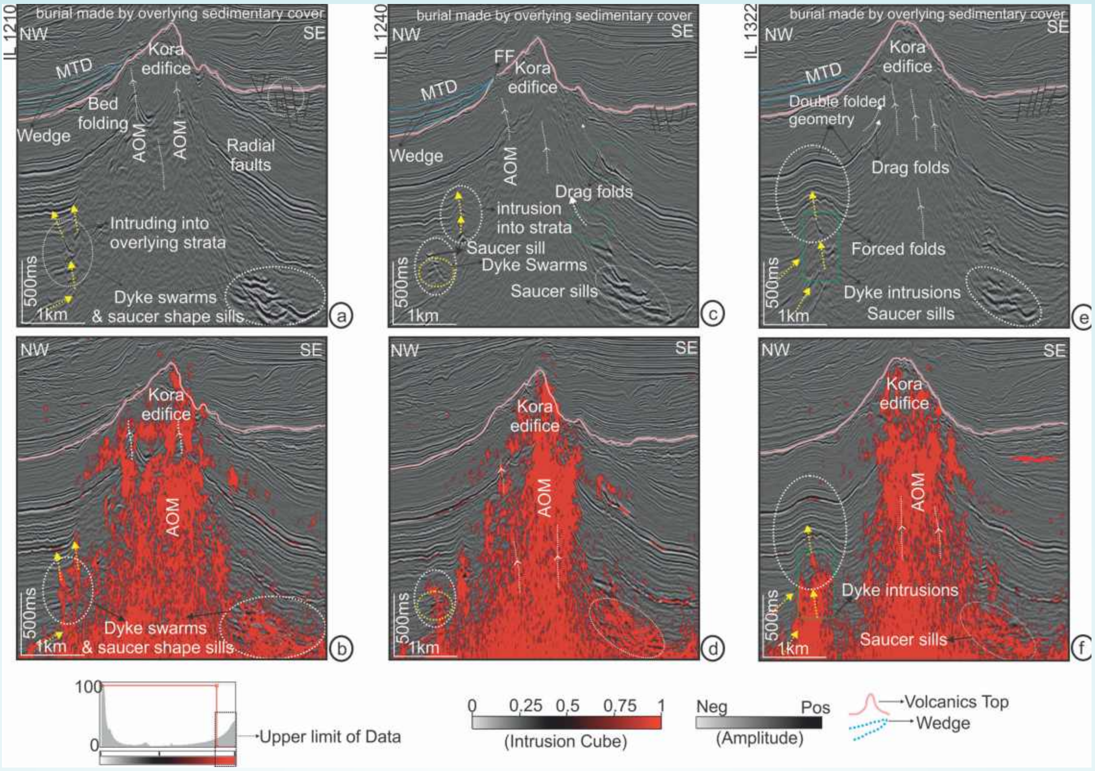

Fig. 2: Interpretation using IC meta-attribute over different profiles of 3D seismic volume in the Kora prospect.

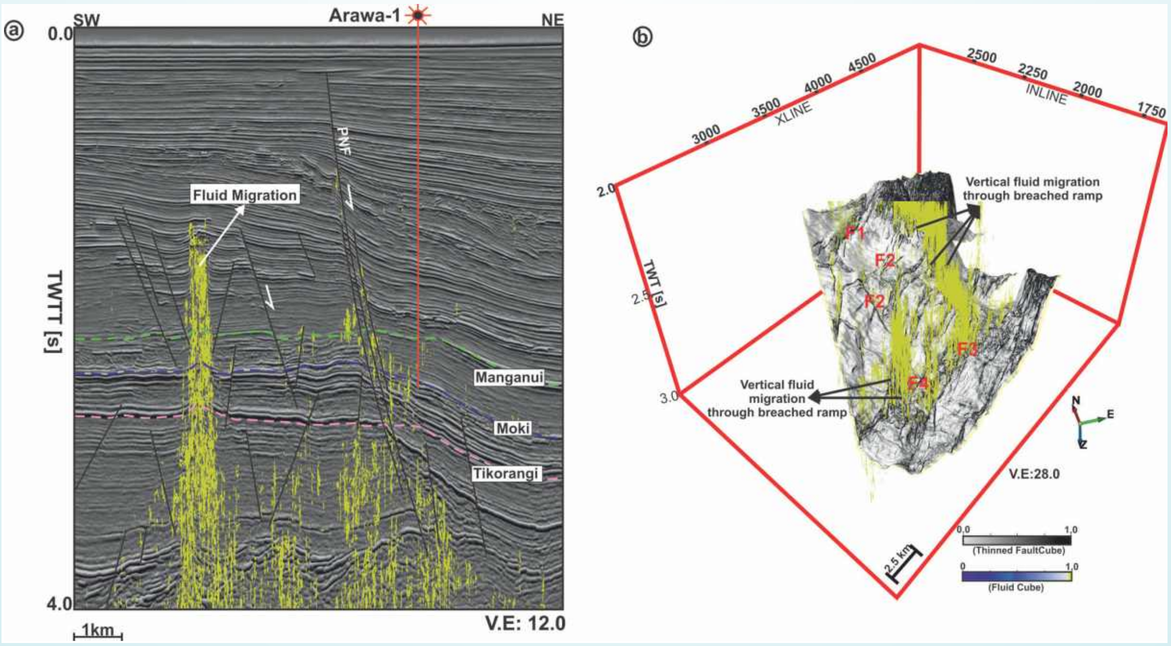

Fig. 3: (a) Fluid Cube meta-attribute revealing fluid migration through hard-linked normal faults. (b) 3D view of breached ramp between faults F1-F2 and F3-F4.

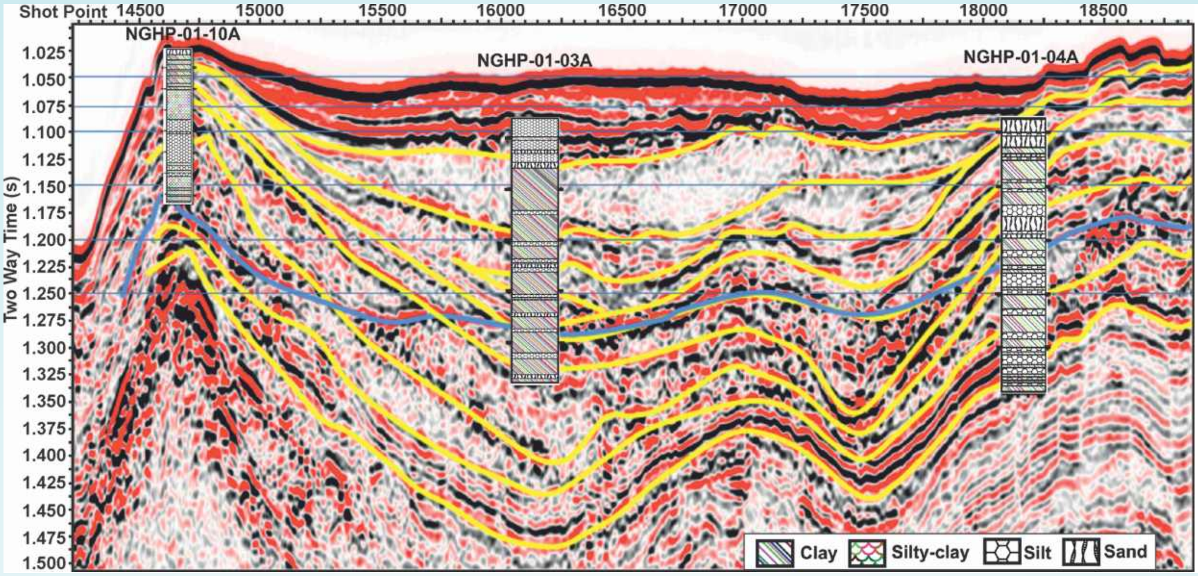

Fig. 4: Correlation of predicted lithology with seismic litho-facies. Blue line denotes the BSR, where yellow lines are indicating various boundaries of sedimentary layers

Hydrates Program in 2006. At first, we apply unsupervised classification method to assess the data dimensionality and number of litho-units, which are further refined by supervised network. This has resulted into four types of litho-units (Fig. 4), dominated by clay (~64%) with some amount of silty clay, silt and minor sand. Very low permeability (<0.1 mD) at all three sites indicate clay-dominated lithology for gas hydrates accumulation. The effects of gas-hydrates have been removed while predicting the lithology. Identified lithologies correlate very well with the seismic section crossing the wells. [Amrita Singh, M. Ojha & K. Sain, 2020. Predicting lithology using neural network from downhole data of a gas hydrate reservoir in Krishna-Godavari basin, eastern Indian offshore, Geophys. Jour. Internat., 220 (3), 1813-1837.].

Academic Pursuits

This year institute published 107 research articles in peer reviewed journals of national and international repute. Additionally, there are 83 publications that are in various stages of publication. We contributed 12 chapters in books published by international publishers and publishing houses. 12 research scholars were awarded Ph.D. degree and 6 Ph.D. thesis were submitted by scholars for award. The laboratories and research facilities are in full swing that has not only been providing analytical database to institute scientists and scholars but also supporting the scientists, academicians and students across the nation. Institute provided summer and winter training to a large number of Master's students representing whole country. As a part of outreach, the institute organized earthquake mitigation drills and demonstrations in several schools and colleges of Uttarakhand. The museum and library of the institute was visited by >5000 visitors. The Institute organized 3rd National Geo Research Scholars Meet that was attended by a total number of 168 research scholars from 40 different organizations, including research institutes, Universities, IITs, and IISERs where 33 Oral presentations and 135 Poster presentations were made.

The institute publishes a biannual SCI journal "Himalayan Geology". This year two regular issues were published successfully. We also brought out a volume of Hindi magazine "Ashmika".

Institute scientists were recognized by award and felicitations at various platforms. Dr Pradeep Srivastava received the Anni Talwani Gold Medal of Indian Geophysical Union, October 2019. Dr (Mrs) Chhavi Pant Pandey has been awarded the Young Scientist Award for best Oral presentation during the 14th Uttarakhand State Science and Technology Congress 2019-2020 (27-29 February, 2020 at UCOST, Vigyan Dham, Dehradun). Prof. Kalachand Sain is conferred with the Sriram Srinivasan Award (2019) by the Association of Exploration Geophysicists. Prof. Kalachand Sain is also conferred with the Prof. Jagdeo Singh Memorial Best Paper Award (2018), given in 2019, by the Geological Society of India. Dr. Perumal Sami received INSA Visiting Scientist Fellowship 2018-19. Dr R.J.G. Perumal has been conferred with the National Geoscience Award 2018 in the field of Natural Hazard Investigation, given in 2019, by the Ministry of

Mines, GoI. Sushil Kumar, Anil Tiwari & team Won Second prize in the poster presentation titled "Source parameters and moment tensors of four earthquakes (Mw: 3.7 - 4.4) triggered in the Kishtwar Region, India" in the National Conference on "Earthquake: Investigation and Instrumentation" organized by the CSIR-Central Scientific Instruments Organization, Chandigarh in CSIR-CSIO Auditorium during 23-24 Sept., 2019.

Other Highlights

Institute strictly followed the Rajbhasha guidelines and published circulars and various office orders in bilingual mode. Hindi Pakhwara was celebrated with due fervour. All national festivals were celebrated with great enthusiasm and various government programs like the Swachch Bharat Abhiyan were supported in utmost manner.

Kalachand Sain
Director

TAT - 1: GEODYNAMIC EVOLUTION OF THE HIMALAYA AND ADJOINING MOUNTAINS

TAT 1.1

Himalayan Deep Image Profiling (HIMDIP) Along Defined Transect

(Gautam Rawat, Naresh Kumar, D.K. Yadav, Devajit Hazarika, P.K.R. Gautam and S. Rajesh)

Geoelectrcial imaging along Satluz Valley

Magnetotelluric time series data was collected at approximately 30 sites along Nahan-Kaurik Chango in Sutlej Valley and from 8 sites in sub Himalaya region along Himalayan tectonic trend in the region of Nahan Salient. Collected MT time series at every site is processed for apparent resistivity curves using median as robust estimators. At few stations electric field recordings were very noisy perhaps due to ongoing hydro-electricity projects and unbalanced power network of the region reflecting larger error bars in estimated impedance tensors. Magnetotelluric transfer function are affected by galvanic distortion effect due to small scale heterogeneities. In absence of information about the dimensionality of regional geoelectrical structure, it is not possible to minimize the effect of these distortions. The apparent resistivity curves were analyzed for dimensionality and decomposition. Swift skew and Bahr's phase sensitive skew indicate the complexity of geoelectrical structure, as none of site response of entire period band can be classified as strictly 2-D except sites at the southern end of profile. Variation of skew parameters therefore suggest that dimensionality of subsurface geoelectrical structure is band limited and varying depth wise. Further shifting of phase response of entire one polarization into the quadrant of another polarization at site (Raksham) between the Main Central Thrust (MCT) and the South Tibetan Detachment System (STDS) further indicate the complex interaction of thrust geometries in the subsurface. Based on the Groom Balley assumption, a R code is developed to decompose the MT transfer function and provide an estimate of distortion parameters. This estimate is further used for decomposing MT transfer function. The code utilized the particle swarm optimization technique for solving the distortion equations as defined by Groom and Bailey in their approach.

Nonlinear conjugate Gradient algorithm was utilized for inverting the decomposed transfer functions along the regional structure. The inverted model as displayed in figure 1 represent estimated 2D geo-electrical model along the profile in Satluz valley. In the estimated inverted model, Intra crustal High conducting layer is present at a depth of 8-10 Km throughout the profile with two intermittent break. It is also observed that the crystalline rocks of the Jutogh Formation have variable thicknesses, which increase progressively toward north. Different thrust zones are well identified and surface features are well correlated with the known geology of the region along the profiles investigated.

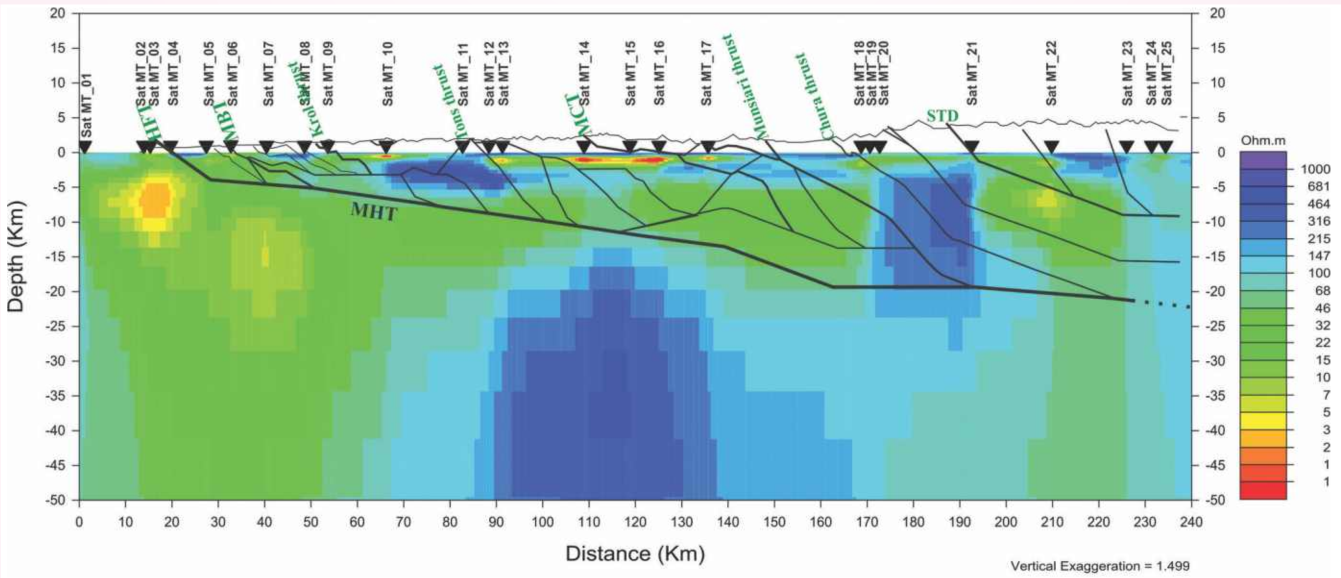

Fig. 1: Geoelectrical section along Satluz Valley with superimposed structural section from Webb et al. 2011.

Further seismicity of the region show that there are two seismogenic zones in the region. One is associated with the Himalayan Seismic Belt (HSB) and another is controlled by the transverse Kaurik-Chango Fault Zone in the Himachal Himalaya.

Identification of a shallow upper mantle discontinuity beneath the Ladakh-Karakoram zone

The investigation of the nature of seismic discontinuities in the Earth's upper mantle is vital for understanding mantle processes. Particularly, the amplitude and sharpness of various mantle discontinuities are critical for understanding upper-mantle phase changes and chemical composition. The mineralogy and composition of the mantle are primarily constrained from geology and petrology of ultramafic rocks, as well as from observations of seismological data. The upper mantle is a peridotitic metamorphic complex composed of mainly olivine minerals, with a lesser amount of orthopyroxene, clinopyroxene, and an aluminous phase (e.g. plagioclase, spinel, or garnet as a function of pressure). The change in pressure and temperature of the upper mantle affects the crystallographic structure of minerals and also leads to the phase transition. Sometimes, such phase transition can produce contrast in seismic velocity which can be detected by seismological data.

We carried out a receiver function study to investigate the upper mantle structure beneath 10 broadband seismological stations of the eastern Ladakh-Karakoram zone. The Ladakh-Karakoram Trans-Himalayan zone is a unique natural laboratory to study such mantle discontinuity. The seismological profile is significant as it cut through the major litho-tectonic units specifically the Tso-Morari Crystalline Complex (TMCC), Indus Suture Zone (ISZ), Nidar Ophiolitic Complex (NOC), Zildat ophiolite Melange (ZOM), Ladakh Batholith, and Karakoram Fault Zone (KFZ) (Fig. 2). The seismograph station recorded about 200 teleseismic earthquakes (M≥5.5, Epicentral Distance: 30°-95°) recorded during 2009-2012. Receiver functions have been computed using these teleseismic earthquakes with the help of the iterative deconvolution method of Liggoria and Ammon (1999). Examples of receiver functions are shown in figure 3. The strong azimuthal variation of the crustal structure has already been reported by Hazarika et al., (2014).

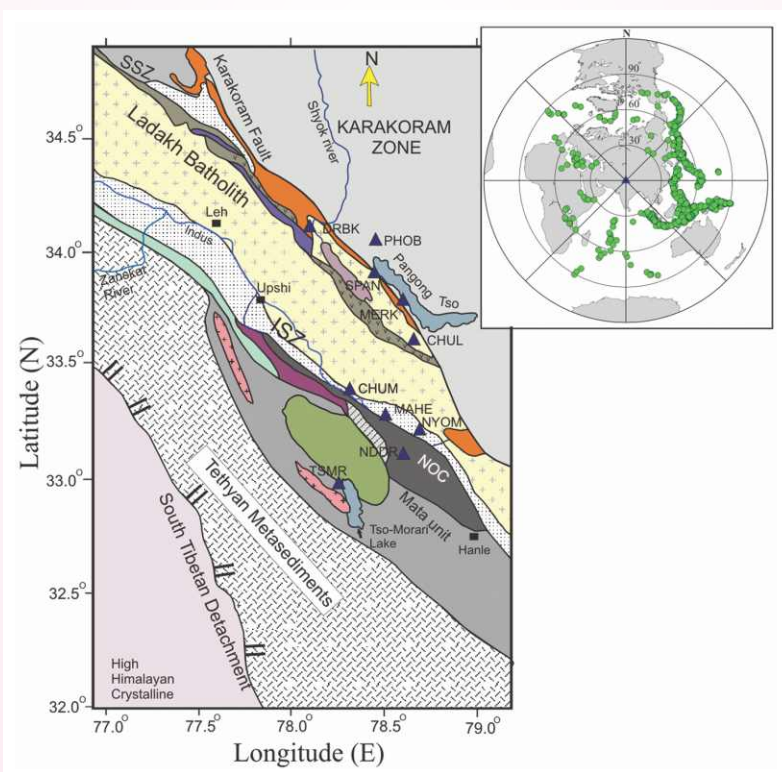

Fig. 2: Simplified geological map of the study area showing parts of the Tethyan Himalaya, Indus Suture Zone (ISZ), and Karakoram zone (Modified after Mahéo et al., 2004; Hazarika et al., 2014). The seismological stations are shown by blue triangles. The inset shows the distribution of teleseismic earthquakes (green filled circles) used for *P*-wave receiver function analysis. Shyok Suture Zone (SSZ), Indus Suture Zone (ISZ) and Nidar Ophiolitic Complex (NOC) are marked.

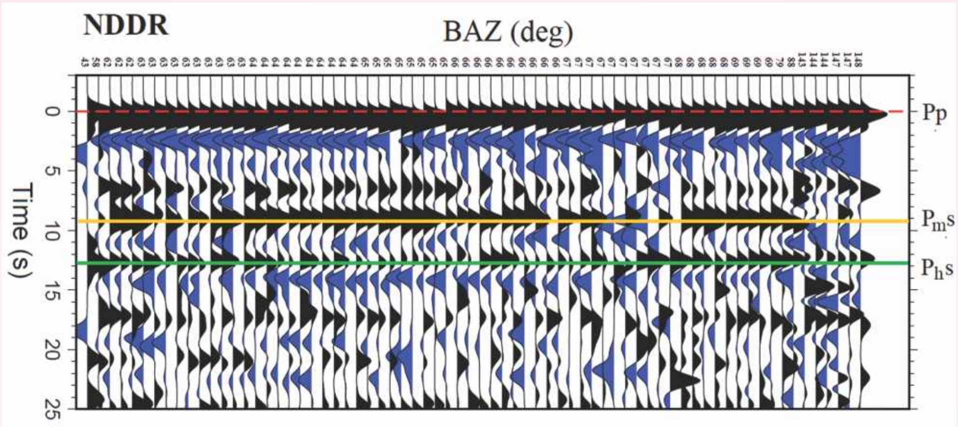

Fig. 3: Receiver functions plot for NDDR station considering Gaussian width 2.5 with increasing back azimuth (BAZ). The P-to-S conversions from the Moho (P_ms) and the Hales (P_hs) discontinuities are marked by yellow and green lines, respectively. The red dotted line indicates the first P-wave arrival (*Pp* phase).

Here, we emphasize on the coherent positive arrival (P_hs phase) distinguishable after the Moho converted P_ms phase. This P_hs is traceable at all stations along the study profile. This positive discontinuity cannot be other mantle discontinuities like Lithosphere-Asthenosphere Boundary (LAB) which is a negative discontinuity and observed at comparatively deeper depth as reported by a previous study in the LKZ (Kumar et al., 2005). In some cases, the P_hs phase is much stronger and coherent than the P_ms phases. The delay time P_hs varies within ~13-14 s. The possible interpretation of this positive discontinuity is the Hales Discontinuity. The Hales discontinuity is reported around the world at 50-150 km depth and inferred as due to spinel to garnet phase transition. The preliminary receiver function image constructed using the Common Conversion Point (CCP) migration method (Yuan et al., 1997) suggests depth variation of the discontinuity within the range 95-120 km depth. Hales discontinuity was first reported as an impedance increase in long-range seismic refraction profiles along with the Early Rise experiment in Continental North America. The discontinuity is a result of the phase transition from Spinel to Garnet and the velocity of P wave increases ~3.5% across this discontinuity. The characterization of this discontinuity has significant importance in understanding the geodynamic evolution of the study region. Further analysis and modeling are under process for detailed investigation.

Seismotectonics of the Kinnaur Himalaya and surrounding Regions

The seismogenetic zones in the Kinnaur region and to its south are mainly located within a depth range of 5 to 25 km (Fig. 4), similar to the general trend of Himalaya. On the basis of the integration of different studies, this region around the epicentre zone of M6.8 of 1975 can be divided into several seismogenic upper crustal parts. The southern part falls in the High Himalayan Seismic Belt (HHSB) where the occurrence of M>5.0 earthquakes is rare. However, in comparison of other similar regions of NW Himalaya, the northern zone in the South Tibetan Detachment (STD) is a unique feature of high seismicity with predominant micro-earthquake occurrence. Seismicity is bounded to the east by the Kuarik-Chango fault zone (KCFZ) which dips steeply to the west. This normal fault aligned nearly NS is transverse to the strike of major tectonic features of the Himalaya and coincides with the surface trace of seismicity along with fault plane solution of M6.8 Kinnaur earthquake. Obtained results from microseismicity and fault plane solutions provide valuable information in understanding the seismotectonic of the region. Fault plane solutions obtained through waveform modelling for 9 seismic events (M>3.0) indicates predominant normal fault mechanism. Moreover, these 7 events located within the northern cluster of microseismcity included with 5 previous available mechanisms indicate normal fault mechanism (Fig. 4b and 4c). In the HHSB, focal mechanisms support the thrust deformation with strike aligned to major tectonics of the Himalaya such as Main Boundary Fault (MBT) and Main Central Thrust (MCT). In 2016, a swarm activity of low-to-micro dimension earthquakes is also reported here, confined within the Kulu-Rampur-Larji window, has predominant thrust mechanisms in the upper crust (Singh et al., 2018). It suggests thrusting of the Indian plate beneath Himalayan wedge along the MHT and major thrusts striking NW-SE direction in this part of the NW Himalaya. Focal mechanism and well-relocated

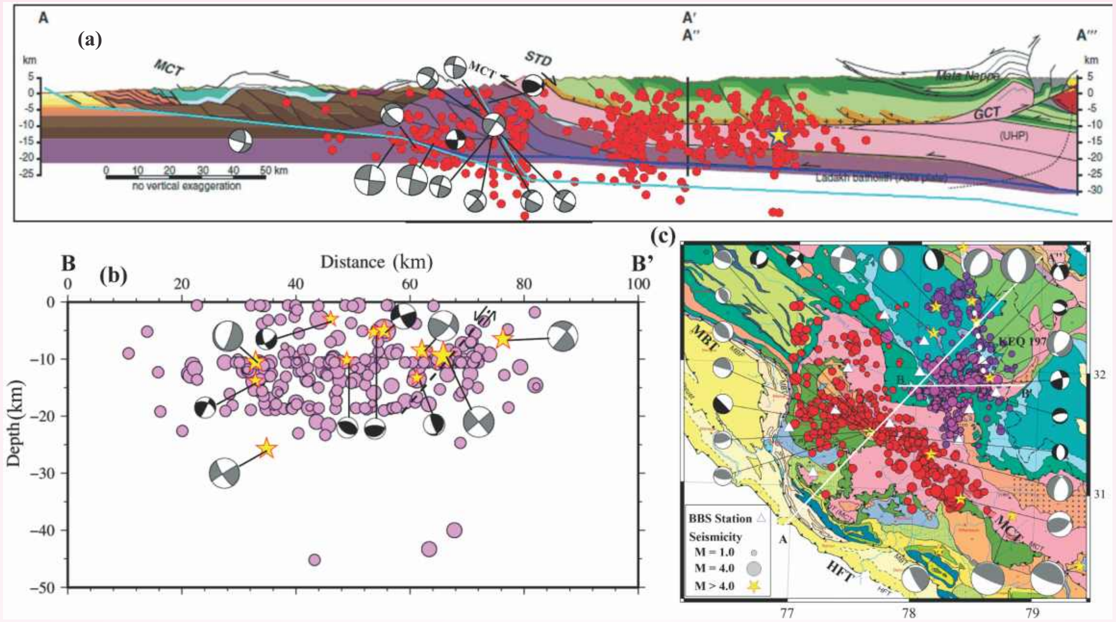

Fig. 4: Seismotectonic model using the refined hypocenter locations, focal mechanism solutions (present - back and past grey beach balls) and the tectonic features along with geological sections. (a) Depth distribution of JHD relocated events along 50 km wide corridor on SW-NE profile (A-A''' across Himalaya is modified after Webb et al., 2011). Blue solid line represents the MHT of Webb et al. (2011) while based on current seismicity the modified MHT and MCT are marked with sky blue line. (b) Depth distribution of seismicity along E-W (B-B') profile of the Kinnaur Himalaya between 78-79 longitude, depth view of FPSs is also plotted and the dotted line marks the fault plane of the M6.8 Kinnaur earthquake of 1975. (c) Epicenter distribution of Kinnaur region (Magenta and violet circles) and rest of the study region (red circles), available FPSs (lower hemisphere beach-balls), geotectonic features (Thakur, 1992), location of two profiles, Kaurik-Chango fault (dotted line). MCT: Main Central Thrust, STD: South Tibetan Detachment, GCT: Great Counter Thrust, UHP: Ultra High Pressure.

hypocentres of microearthquakes indicate a spatially variable mode of deformation that departs from thrusting in the northern part. It also support the interpreted and existing tectonics of the study region and therefore sub-surface upper crustal deformation highlight the ongoing tectonics.

Role of site Effect for the evaluation of attenuation characteristics of seismic waves in the Kinnaur region, NW Himalaya

The site effect and attenuation studies are carried out for the Kinnaur region and surrounding parts of the Northwest Himalaya. The Horizontal to Vertical Spectral Ratio (HVSR) technique is applied to estimate the site effect and the results are useful for seismic hazard studies. The earthquake records are influenced by the site effect depending on soft sediment thickness beneath the recording sites. The study region of Tethys and higher Himalaya has high seismicity in a localised zone. Earthquake of magnitude range 1.6-4.5 recorded at local epicentre distance through 10 broadband seismic stations are utilized. The records corrected for the site effect are used to estimate P (Qp), S (Qs) and Coda (Qc) wave quality factor which is inversely related to seismic wave attenuation. The regional frequency dependent attenuation relations are established in the form of $Qc(f) = (29\pm1)f^{(1.01\pm0.05)}$, $Qp(f) = (38\pm5)f^{(1.1\pm0.06)}$ and $Qs(f) = (74\pm11)f^{(1.17\pm0.01)}$. Higher Himalaya Crystalline and Tethyan Himalaya, the two main geological units of this region are separated from each other by the South Tibetan Detachment System. Computed frequencies have comparatively low resonance value for the data of northern part i.e. Tethys Himalaya. It supports the presence of low grade meta-sedimentary rocks, which suggests high seismic hazard potential zone as compare to Higher Himalayan Crystallines (HHC). Similarly, higher rate of attenuation towards the northern side of STDS suggest close resemblance with the geology and the uppermost subsurface strata of these two regions.

Subsurface structure investigation using Ambeint noise and Surface wave tomography

The inverted shear wave velocity models obtained from Rayleigh wave data of ambient noise and moderate to strong earthquakes indicate a high variation in the depth of the Moho discontinuity. It indicates broad-scale features obtained through earthquake data and high-resolution features in the localised zone of collision based on ambient noise. A profile perpendicular to major tectonics provides a view of Indian plate Moho dipping towards north and the Eurasian plate dipping south (Fig. 5a). A broad low velocity strata is obtained in the middle and lower crust in the part of Karakoram Fault and Tibetan plateau region. It may be the manifestation of partial melt/warm zone due to collision tectonics. It suggests that the middle-to-lower crust may decoupled from the upper crust and deforming it continuously. In a localized part north of western syntax and west of Karakoram fault, the low velocity seems to continue to a deeper section below ~85-90 km. It was not possible to obtain the Moho depth deeper than 90 km using the present data. However, there is a continuity in the occurrence of even intermediate focus earthquakes upto a depth of 200 or deeper. It indicates that the part of the Indian plate submerged into the mantle. The high resolution ambient noise tomography shows the geometry of the detachment for ~125 km length beneath Himalaya aligned to southwest-northeast direction (Fig. 5b). This sub-surface structure favours the results obtained by Yin (2007) based on geological investigation. A thin zone of low velocity for the part of ~80 km detachment may suggest a zone of aligned ainostropic minerals or fliud inclusion. It has the evidence of existence of double ramp structrue for the geometry of Main Himalayan Thrust.

Micro-earthquake activity in and around Chandigarh-Ambala sub-surface ridge region are studied through local Broadband Seismic (BBS) Network of Wadia Institute of Himalayan Geology (WIHG) for the period November 2018 to April 2019. Six Broadband (BBS) seismic stations (e.g. SATN, JKH, KTH, ADBD, ZND and SAMN) which are already deployed in the Chandigarh-Ambala ridge region, each of seismic station are equipped with Trillium 240 sensors and Taurus digitizer (Nanometrics, Canada Inc.) Local and regional earthquake events are extracted from continuous waveform digital record for further processing and analysing. For better location of earthquake events we have included the data recorded by other adjoining seismic station (BNJR, and SPLO). The data are selected on the basis of high signal to noise ratio (SNR) and with minimum errors in the estimation of hypocentral parameters. The velocity model developed by Parija et. al (2016) with Vp/Vs ratio of 1.75 is used for locations. About 60 local and 80 regional events are extracted and located using Seisan Software, the local events have the magnitude range

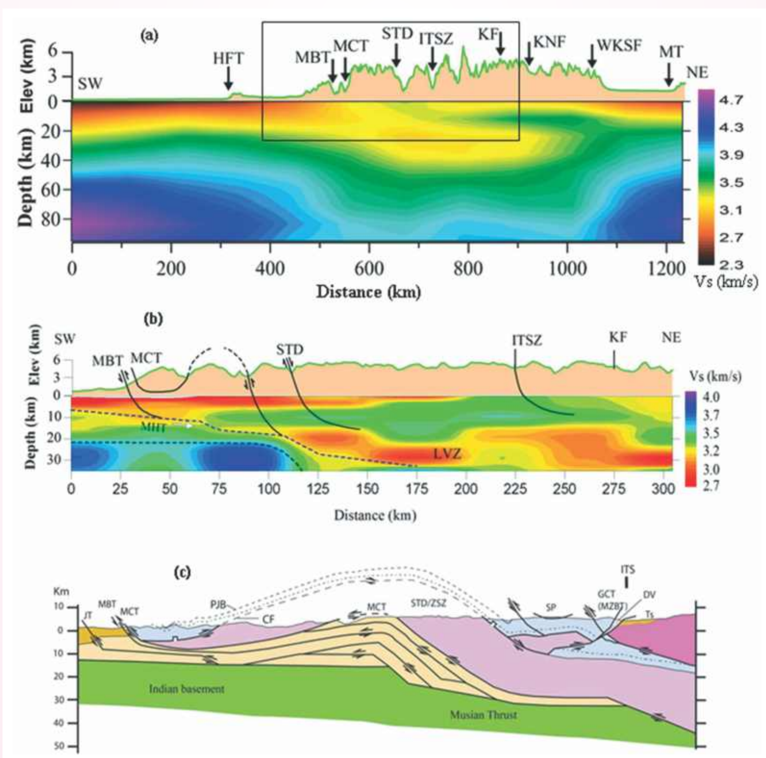

Fig. 5: Vertical Vs sections (a) based on the surface wave tomography by Kumar et al. (2019) SW-NE cross-section (Fig. 9 of that paper) perpendicular to major tectonics (b) cross-section obtained from the inversion of ambient noise data, it is the upper most 30 km strata parallel to profile AB shown in a) with rectangle. (c) Geotectonic cross-section based on structural study by Yin (2007).

from 2.5 to 5.1 and depth distribution is up to 48km. Majority of earthquakes are concentrated near Mahendragarh-Dehradun fault, which trends approximately in North-south direction. Four earthquakes are selected for the determination of Fault plane solution using waveform inversion technique (ISOLA). The fault plane solution of a earthquake which have the magnitude with M=5.1 have been determined using ISOLA (Sokos and Zahradnik, 2007). The Seismic moment obtained is 1.837e+09 through averaging the seismic moments from all the components of the recorded stations. The obtained solution is based on maximum correlation between time shift and source position. The solution has a centroid depth of 45km for the time shift of 2-25 sec having a DC% of 65. It is a Strike-slip faulting type with little amount of normal. The two nodal planes NP1 and NP2 are trending in NNW-SSE and NE-SW directions respectively. Nodal plane-2 is considered as fault plane since this nodal plane trends in NE-SW direction, which is correlatable with Mahendragrh-Dehradun Fault.

This year continuous GPS data in the Sub-Himalayan region of Nahan salient has been acquired and studied. The acquired data has been processed using GAMIT/GLOBK and obtained continues positional anomalies in three components. The Sub-Himalayan section of Nahan salient lies right over the highly locked portion of the MHT where the coupling ratio is quite high. Besides in this section the intermittent major thrust zones are relatively close and the topography shows abrupt rise with respect to the frontal part. Thus the region may accumulate substantial amount of stress and the strain energy should be used to produce significant horizontal and vertical movements and the same could be observed in the GPS measurements. However, the processed continues time series data from the Nahan salient show annual periodic displacements in both horizontal and vertical components apart from the general linear trend. The cyclic nature of the vertical displacement is quite predominant compared to the respective horizontal components. Among the horizontal components the N-S displacement component is quite predominant with respect to the E-W component. The N-S component shows advances and relaxations in the relative velocities of this part of the crust. The amplitude of periodic horizontal displacements in the North-South component or perpendicular to the Arc component is 10 ± 2 mm, which is predominant compared to the East-West or along the Arc-component. The perpendicular to the Arc periodic displacement suggest periodic changes in the surface velocity at the frontal part of the Nahan salient that situated right over the locked portion of the MHT. The periodicity of periodic displacements in both horizontal and vertical components last around 3 to 4 months annually from the month of May to August. However the amplitude of the periodic displacement in vertical component is around 20 ± 2 mm which consist of both tectonic and hydrological factors for the net displacement. The uplift of the surface commence during the month of May and proceeds to negative displacement or subsidence which last till the end of August. The pre-monsoon hydrological unloading or depletion of the ground water causes surface uplift while the subsequent ground water recharge during monsoon months lead to subsurface loading and consequent subsidence of the crust. Thus the hydrological loading and unloading of the crust is one of the factors that cause variable relative plate movement in the Sub-Himalayan section of the Nahan. In fact such relative changes or secular changes in the crustal velocities are observed not only in the Sub-Himalayan section of Nahan but also at other GPS stations in the lesser and higher Himalayan regions at various amplitude ranges.

We considered these changes while understanding an overall relative shortening of the Nahan section with respect to the Tehyan Himalayan station Hanle as shown in the figure 6.

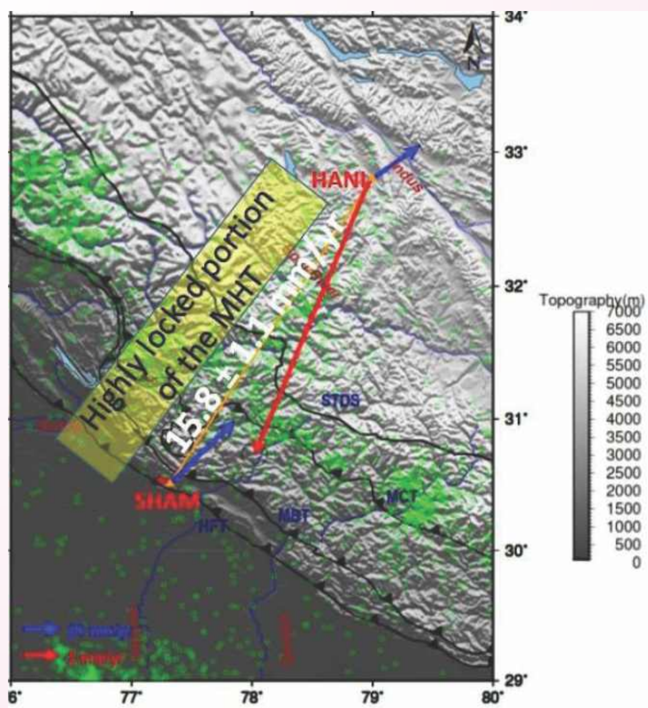

Fig. 6: GPS measured surface shortening rate between the Nahan site (named as SHAM in the ppt) in the Sub-Himalaya and the Hanle station in the Tethyan Himalaya.

The red arrows show the velocity vectors from the Nahan and the Hanle sites with respect to the India pole (Ader pole). The relative movement of the Nahan station along the Frontal Arc is abysmally low and oriented towards North-West. The overall surface shortening rate across the Nahan Salient from the Frontal and up to the station at Hanle is 15.8 ± 1.2 mm/yr and mainly directed along SW towards the frontal part. Current shortening rate of ~ 15.8 mm/yr (shown in white fonts in the figure) which matches with the direction of the compressional axis. Earlier our results on the estimation of Gravitational potential energy gradient across the Nahan salient also shows the GPE gradient is quite erratic, especially within the Lesser Himalayan region. Here the negative gradient shows the region is under compressive stress and it matches with the compressional regime observed through GPS data.

TAT 1.2
Fluid-P-T-t evolution of Leopargil Gneissic dome, Himachal Pradesh

(H.K. Sachan, Aditya Kharya and Saurabh Singhal)

Ten days fieldwork was carried out in the month of Nov 2019 in the Leo-pargil, Khab area along the Sutlej valley. We have done mineralogical study that includes petrography, mineral chemistry and thermodynamic modelling as well as isotopic study of migmatititc zircon.

The petrography reveals that the migmatite is comprised of plagioclase (15~20%), K-feldspar (20~25%), quartz (40~45%), and biotite (10~15%), with minor amounts of muscovite, garnet, apatite, zircon and FeTi oxides. The mineral chemistry data of garnet reveals that the MnO is increasing from core to rim while MgO is showing constant variation from the core to rim. CaO is increasing from core to rim. The estimated p-t condition of migmatitzation in Leo-pargil area is prograde (600 ± 25°C, and 6.0 ±0.2 Kbar), peak (750 ± 25°C, and 7.8 ±0.2 Kbar) and retrograde P-T condition (670 ± 25°C, and 4.7 ±0.2 Kbar These P-T condition of migmatitization is estimated using thermodynamic modeling.

The REE study has been carried out to trace the nature of protolith of zircons. The REE content of analyzed zircon shows positive Ce anomalies and negative Eu anomalies. Majority of the zircon show enriched HREE profile while a few zircon show flat LREE profile. Study of zircons as majority of the zircons show Enriched HREE profile while a few zircons show flat LREE profile. WIHG SR11 Zircons have Th/U ratio in between 0.0075 to 0.9 whereas WIHG SR14 zircons have a ratio in the range of 0.087 to 0.89. The Th/U ratio in the zircons of SR9A varies in between 0.144 to 1.258, whereas the WIHG SR1 sample shows Th/U ration in between 0.2 to0.86 and Th/U ratio in WIHG SR3 vary in between 0.008-0.49. The high Th/U ratios (0.2-1.5), positive Ce and negative Eu anomalies, as well as enrichment in HREEs in some of the studied zircon are consistent with magmatic origin.

U-Pb geochronology, Hf isotopes, and trace elements chemistry of zircon grains from the migmatites of upper Satluj valley, North-West Himalaya, reveal a protracted geologic evolution and constrain the anatexis and tectono-thermal processes in response to Himalayan orogeny. U-Pb geochronology and εHf record three distinct periods of zircon growth in the migmatite (1050-950, 850-790, and 650-500 Ma). The 1050-950 Ma zircon population supports provenance from magmatic units related to the assembly of Rodinia. The 850-790 Ma zircon were likely derived from Arabian Nubian Shield, although Hf isotopes require the reworking of older crust than is usually associated with this source area. The 650-500 Ma zircon population suggests the source from the East African Orogen and/or Ross-Delamerian Orogen of Gondwana. Minor amount of Paleoproterozoic grains were likely derived from the Indian craton. One sample yielded a discordia lower intercept age of 15.6 ± 2.2 Ma indicating the timing of decompression melting during crustal extension process along Southern Tibetan Detachment.

TAT 1.3a
Crust-Mantle interaction in continental subduction zone and their role in Himalayan tectonics

(Barun K. Mukherjee, Koushik Sen and Santosh K. Rai)

Plate subduction is the most important geological process that carries continent and oceanic lithosphere into the deep Earth, which changes dynamic interior of the Earth. The study of Subduction zone complex including ophiolite sequence, ophiolitic melange and quartzofeldspathic gneiss dome, is primarily selected to understand the fundamental geological issues such as the formation and evolution of overlying oceanic sediments, subduction of low density continental rocks leading to crustal recycling process and continental crustal growth. In the eastern Ladakh, field geometry of Zildat Ophiolitic mélange (ZOM) is undertaken to understand the shallow-level exhumation history of this unit and the adjoining ones. The study reveals the Zildat Fault initiated as a normal fault but reactivated as a reverse fault with SW vergence, an example of inversion tectonics during collision. The NOC is un-metamorphosed and is devoid of penetrative tectonic fabric. The ZOM is a bivergent wedge having components of accreted oceanic crust. We propose a two-stage exhumation of the ZOM assisted by TMC with NOC as a barrier. The TMC exhumed with respect (i) to the ZOM when the Zildat Fault activated as a normal fault. The ZOM accommodated the space for the TMC by acting as an extensional detachment. Subsequently, in response to achieve isostasy by the TMC dome. The Zildat Fault (ii) reactivated as thrust fault, the extensional detachments imbricated and thus the ZOM exhumed as a 'pop-up' block bound by opposite dipping thrusts. Adjacent to tectonized mélange the carbonate veins of ophiolite sequence is studied to understand the crustal recycling process, it show that the fluids with high radiogenic $^{87}Sr/^{86}Sr$ values and enriched in elemental Sr penetrated into the Sr-poor peridotite to produce these carbonate veins, suggests involvement of continental crust-derived fluids which is sourced from the adjacent gneissic dome. The zircons study from Gneiss dome of Tso Morari at the Indus Suture Zone have offered insight into the origin and evolution of low density continental rock has suffered ultrahigh-pressure condition. It challenges the general understanding and agreement that the buoyancy could only be the mechanism by which Indian continental plate sink beneath Eurassian plate. The zircon study extends the ability to successful linkage between metamorphic stage and identifying possible stages of zircon growth, correlated by inclusion patterns or reaction textures. This study have reveals that the Indian continental rocks coherently participated in the deep subduction process along with mafic eclogite, which subsequently recycled back following the same path as followed by eclogite enclaves.

TAT 1.3b

The crust-mantle interaction with reference to Himalayan Orogeny…. Indus Suture Zone (ISZ)

C. Perumalsamy and Pratap Chandra Sethy

The mafic enclaves and granite or granitoids were sampled for geochemical, mineralogy and isotopic studies from the southern margin of Ladakh granitoids in eastern ladakh. The study was carried out to determine the nature, character and tectono-magmatic evolution of Ladakh granitoids. Mafic enclaves (Monzodiorite) show high mafic elements (Ca, Fe, Mg, Mn) than felsic granite (Q-monzonite, granite, granodiorite, fractionated granite), the granites show enrichment of felsic elements (Na, K), except K. They (mafic enclave and granitoids) are I type, metaluminous to peraluminous, calcic-alkalic to alkalic- calcic nature of derived from calc-alkaline The presence of negative Eu anomalies indicates plagioclase main component in their source. Further, the partial melting of mafic rocks at amphibolite-rich igneous oceanic crust yield different degrees of fractionation crystallization and produces different type of granites at the subduction zone (< 600 km). We have classified three types based on their Eu anomaly and tracer elemental and REE patterns, such as, i) Type-I granite or early granite (high LREE and low HREE, weak or negligible Eu anomalies), type-II granite or mature granite (High LREE and depleted HREE, remarkable Eu and Tm anomalies) and type-III granite or fractionated granite (Equal proportion of LREE and HREE and Strong positive and negative Eu anomalies) granite by tracer analysis including REE (Fig. 7b, c, d). The positive Eu and negative Tm anomalies indicates their origin from amphibole rich mafic source in lower continental crust. the different magmatic pulses were reported in Ladakh granitoids by earlier workers.

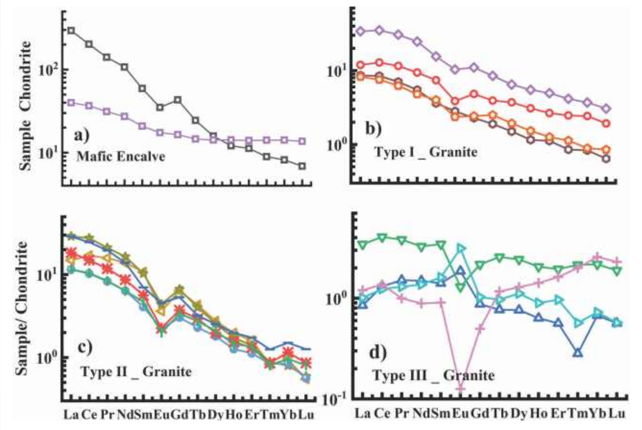

Fig. 7: Chondrite normalized diagrams, a) mafic enclave, b) earlier or type-1 granite, c) mature or type-II granite, d) fractionated granite or type-III granite.

The mafic enclave consists of monzodiorite, which has high LREE, LILE (Rb, Ba, Th, U) than HREE and HFSE (Ti, Nb, Zr, P) and low U/ Nb, Ce/ Pb ratios, which is produced by upwelling asthenospheric mafic melts at the lower crustal rocks by peritectic reactions (Fig. 8a). The plagioclase mainly controls the LILE, LREE, while amphibole fractionation causes the depletion of MREE, HREE in mafic enclave. The enrichment of LREE, LILE, Pb, Th than HREE, HFSE is common in volcanic arc granite in intra oceanic subduction zone, vary chemical composition depending upon the composition of subducted crust (lower to upper). The fractionation of accessory and some felsic and mafic minerals leave the variation tracer elements in granitoids (Fig. 8b). The variable fractionation of granite shows high positive anomaly (+2.64) to weakly negative Eu anomaly (-0.19).

The high negative ε Nd value in granite indicates that they are sourced from highly fractionated felsic lower crust, except LBH-12 (upper crustal origin) (Fig. 10).

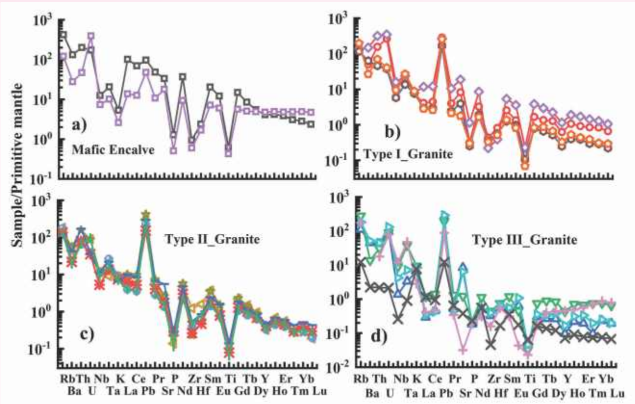

Fig. 8: Chondrite normalized diagrams, a) mafic enclave, b) earlier or type-1 granite, c) mature or type-II granite, d) fractionated granite or type-III granite.

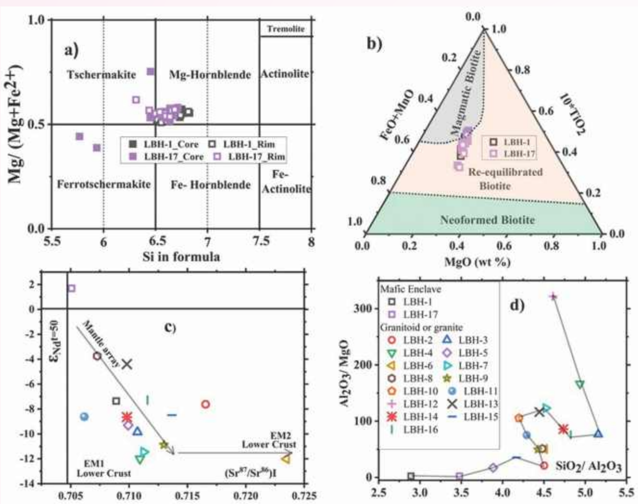

Fig. 10: Chemical variation diagram for Mafic enclave and granitoids, a) amphibole classification diagram, b) biotite classification, εNdt=50 Ma Vs. ($^{87}Sr/^{86}Sr$) I diagram, fractional crystallization diagram (d).

TAT 1.4

Tectono-metamorphic, exhumation and mineralization in Himachal, Garhwal and Sikkim Himalaya

(Rajesh Sharma, A.K. Singh, S.S. Thakur, Saurabh Singhal, Paramjeet Singh and Aliba AO)

Geology, Structural, Metamorphic and Mineralization studies along the Mandi-Kullu-Manali-Rohtang transact of Himachal Himalaya, NW-India

A detailed field-based study was carried out in Mandi-Kullu-Manali section (Fig. 11) along the Beas river valley from the Main Boundary Thrust (MBT) to the

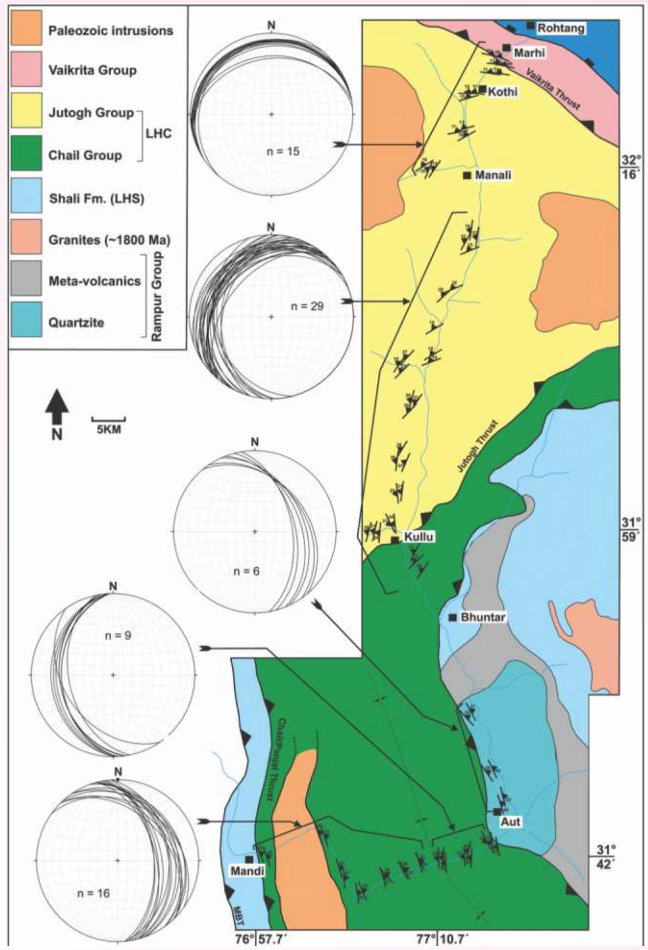

Fig. 11: Geological and Tectonic map of the study area along the Beas Valley of Himachal Pradesh, NW-Himalaya (Modified after Thakur, 1992).

South Tibetan Detachment System (STDS). This dip-section provided an excellent opportunity to study the structural imprints, deformation pattern based on the shear-sense analysis, magmatism, metamorphism, and the occurrences of economic minerals in the region. Two different phases of metamorphism and deformation are evident in all three litho-tectonic units viz. Chail, Jutogh and Vaikrita Groups present in the section (Fig. 11). The structural studies from the Chail Formation from Mandi-Larji section reveal two phases of deformation: (i) The first phase was pre-syn orogeny wherein quartz veins intruded and folded as open to close folds. (ii) The second phase indicates the post-orogenic deformation which is clearly seen in the deformed or folded quartz veins and the formation of recumbent/overturned folds. The second phase deformation also indicates top-to-south shearing along the Chail/Punjal and Jutogh Thrusts. Some important features observed are presented in figure 12.

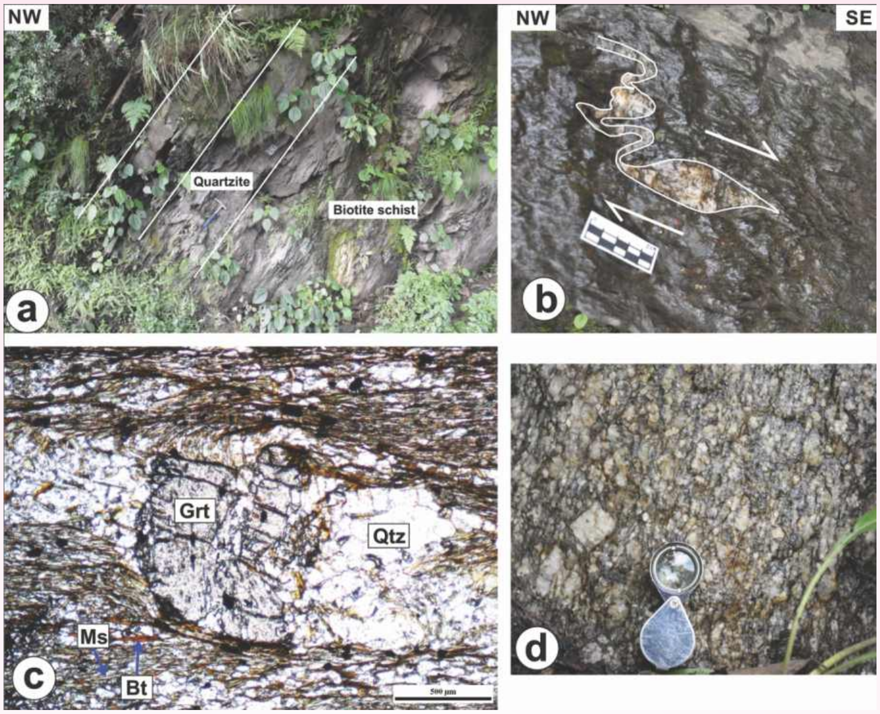

Fig. 12: (a) Chlorite schist with 2-3 meter wide beds of foliated quartzite representing Chail Formation. (b) Top-to-S/SE ductile sheared sigmoid clast of quartz observed within the chlorite schist indicating two phases of deformation with top to south sense of shearing. (c) Photomicrograph showing garnet poikiloblasts contaiing inclusions of quartz and opaque minerals, and wrapped by muscovite + biotite with dominant foliation. (d) Field photograph of the porphyroclasts in the Paleozoic Mandi Granite.

The metamorphic study suggest that the core part of Pandoh syncline was metamorphosed upto biotite grade of metamorphism, whereas both the limbs of the syncline attained garnet-grade of metamorphism. The garnet zone consists of garnet, biotite, muscovite, chlorite, plagioclase, epidote, quartz, tourmaline and oxides (opaques). The poikiloblasts of garnet contain inclusions of quartz, while the opaque minerals are wrapped by the dominant foliation of muscovite + biotite (Fig. 12c). Within this dominant foliation, an older foliation of chlorite + muscovite association is also observed. Further, the Kullu area indicates probably a higher grade of metamorphism compared to the lower section i.e. Mandi-Larji section, as indicated by larger garnet grain varying upto 1 cm in size. The quartz veins parallel to the bedding planes are folded concurrent with the shearing, and clearly shows top-to-south shearing sense. The garnet poikiloblast are wrapped by mica flakes defining the foliation and the main foliation of the host rock is also folded in some domains in Kullu area.

The intruded quartz veins are intensively deformed, sheared and folded. The sense of asymmetry of sigma (σ) type 'tails' of quartz porphyroclastic material is seen in the gneisses. The Delta-types (δ) ductile sense of shearing (top-to-south) are seen, which are developed because of rapid rotation of the core-object and production of some recrystallized material. In the section between the Manali-Rohtang, the mylonitic gneisses are exposed along the road. The granitic gneiss of Vaikrita Group are compact and mylonitized in nature, with some intrusive leucogranite and Paleozoic granitoids. The intruded quartz veins are ~2.0-2.5 cm thick and contain some mafic material accumulated within the hinge zone as well as in the limbs of folded quartz veins (Fig. 13).

U-Pb Geochronology and Geochemistry of Chaur Granitoid Complex

The magmatic rocks of Chaur Granitoid Complex (CGC), Himachal Himalaya are studied to understand their Tectono-magmatic evolution. The newly obtained U-Pb (zircon) geochronology results for granitoid samples yield age between 766 and 1080 Ma, with a few younger phases and older inherited ages. The obtained zircon U-Pb ages of one sample gives the two prominent age spectra for $^{206}Pb/^{238}U$ with weighted mean age of 826 ± 4.97/9.74 Ma (MSWD = 0.65, n = 8) and 868 ± 6.21/12.17 Ma (MSWD = 1.28, n = 7). Similarly, another granite of CGC gives the weighted mean age of

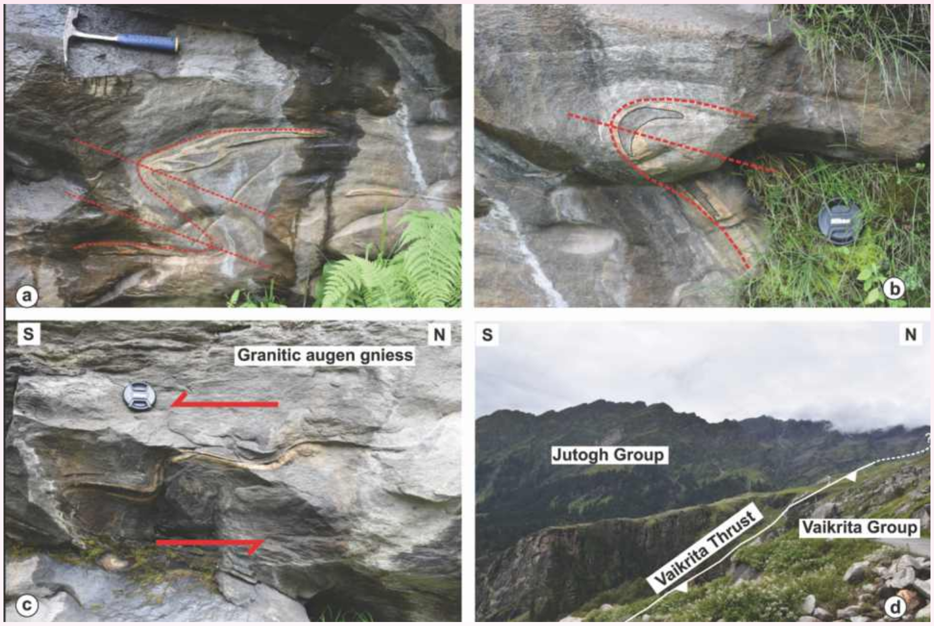

Fig. 13: (a-c) The compact and mylonitized granitic gneiss of Vaikrita Group with some intrusive Leuco-granite and Paleozoic granitoids. The intruded quartz veins with accumulates of mafic material. (d) Vaikrita Thrust between Paleoproterozoic rocks of Jutogh Group and Paleozoic-Ordovician granitic gneiss of Vaikrita Group.

929 ± 6.48/12.70 Ma (MSWD = 1.28, *n* = 11). The granitic gneiss of the Jutogh group also offer two prominent age spectra for $^{206}Pb/^{238}U$, with weighted mean age of 861 ± 8.27/16.21 Ma (MSWD = 0.31, *n* = 10) and 932 ± 10.0/19.6 Ma (MSWD = 1.57, *n* = 8). The whole-rock geochemical data suggest calc-alkaline nature of all six samples, attributing a subduction-related accretion setup. The depletion in the Nb, Sr, P and Ti in CGC indicates a magmatic arc type magma. Based on the whole-rock geochemical data and U-Pb (zircon) ages (~ 930 Ma age of crystallization of CGC) of the two different granites of the CGC and the granitic gneiss rocks of Jutogh Group, it is concluded that CGC was intruded during the Grenvillian orogeny in the northern marginal part of the Indian plate (Fig. 14). It is also envisaged that the unidentified microcontinents, which were present in the northern margin, collided with the Indian plate and the subduction process coincides with the onset of the Grenvillian orogeny during the Neoproterozoic.

Mineralisation in the Kullu area of Himachal and in Sikkim Himalaya

The copper, nickel, and cobalt mineralisation in Naraul-Danala area in Garsah valley and the lead copper and zinc mineralisation at Uchich in the Parvati valley are investigated. The mineralization near Naraul appears significant wherein widespread occurrence of chalcopyrite, pyrite, malachite, covellite and azurite are visible on the outcrops. The sulphide mineralization is seen in the veins and as disseminations. Further, the sulphide mineralization is also noticed atleast in three locations near Behali and Spangini in the Sainj valley. It is localized in the shear zone, with the host rock as quartzite and associated with metabasics. In Chinjjra and Dharmoar village in Parwati valley, the quartzites have patches of chlorite- fuchsite, oriented quartz veinlets, and very fine lamellae and veinlets of hematite. The reddish, greyish and white quartzite consists of specks and streaks of chalcopyrite and hematite with limited localised encrustations of malachite, azurite in uraniferous quartzite. The Uchich sulphide mineralization in Parwati valley is promising. Its mineralogy including the alteration mineralogy have been studied in detail. The polymetallic sulphide mineralisation in the area occurs in hard, metamorphosed and highly jointed vitreous massive Manikaran Quartzite. The fluid inclusions are filled with complex C-H-O-S fluid.

The field traverses were also taken in the mineralised localities of Rangpo, Rorathang-Pachekhani and Dikchu-Lindok section in south Sikkim. The host rocks of the vein type mineralization at Rangpo and Dickchu are mainly quartz-chlorite-sericite-muscovite-biotite schist, with subordinate metavolcanics. The mineralized samples consists of chalcopyrite, pyrrhotite, sphalerite, galena, arsenopyrite and pyrite, as primary phase, and

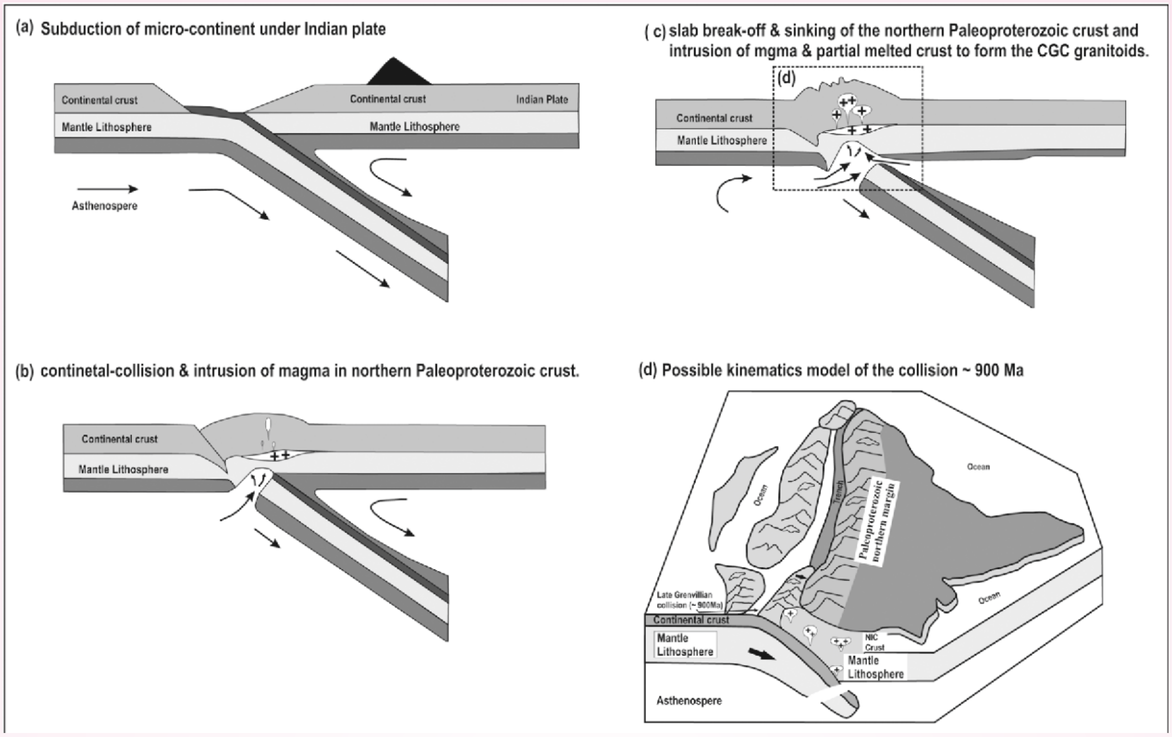

Fig. 14: The sequence of events on slab breakoff on collision of microcontinent, (a) collision and subduction of oceanic lithosphere of microcontinent under the Indian plate cratons; (b) collision and subduction of continental crust under the Indian plate; (c) slab breakoff and sinks of northern crust and intrusion of magma and partial melt of the lower crust to form the porphyritic granitoids of CGC (Sequence of events after Goswami and Bhattacharya, 2014); (d) the possible configuration and kinematics of Indian continent during the Neoproterozoic magmatic events.

covellite, azurite and iron oxides as secondary ore minerals. The quartz forms the major gangue mineral. The fluid inclusions study of coeval quartz show that aqueous-carbonic and pure carbonic fluid inclusions are abundant in the mineralized quartz.

Metamorphic and thermochronological studies of the Jutogh Group of rocks

The tectonothermal evolution of the crystalline rocks of the Mandi area, Himachal Himalaya, has been investigated using metamorphic study and fission track dating. The prograde clockwise P-T path inferred from the outer crystalline rocks NW Himalaya indicates an increase in both pressure and temperature during loading. The inferred P-T path is consistent with heating as a result of over thrusting of the hot overlying unit. Such P-T paths are consistent with the “critical taper” thermo-mechanical model rather than the widely accepted channel flow model. To quantify the exhumation history, granitoids and metapelites samples were studied along Mandi-Manali section, Beas Valley, NW Himalaya. After the Thermal irradiation from the FRM-II (Germany) total 25 apatite and 5 zircon samples for Fission Track Thermochronology have been analysed. Out of these 25 samples, the obtained apatite fission track (AFT) ages range between 1.9 ± 0.2 and 4.9 ± 0.9 Ma. Three AFT ages from the Mandi area (including Granite body) are between 2.8 ± 0.5 and 4.9 ± 0.6 Ma, whereas AFT ages from the Jutogh Group range between 1.9 ± 0.2 Ma and 3.0 ± 0.3 Ma. Based upon the AFT age obtained from close proximity of Panjal thrust hanging wall, the reactivation of Panjal thrust/MCT ~3Ma has been suggested. Additionally, the AFT ages obtained farthest to Punjal/MCT are older (>5Ma). It means the last tectonic activity along the Punjal/MCT has been observed ~3Ma.

Petrology and Geochemistry of Jaspa Granite, Bhaga Valley, Himachal Himalaya

The Jaspa granite pluton, exposed in the Bhaga valley of Himachal Himalaya, is outcropped as a sheet-like kilometer-scale plutonic body characterized by its coarse- to medium-grained porphyritic texture. The Jaspa pluton encloses genetically related sporadically distributed magmatic enclaves ranging in size from a few centimeters to tens of centimeters. Geochemical characteristics including the presence of two micas, high contents of SiO_2, Al_2O_3, A/CNK, A/NK, Rb and low

CaO, Sr contents, along with strong depletion in HFSE, suggest that the Jaspa granite that intruded the Proterozoic rocks of Tethys Himalaya, is of peraluminous S-type granite affinity generated by the partial melting of crustal material. The LA-ICPMS zircon U-Pb ages of Jaspa granite suggest that two principal stages of magmatism, which took place during ~570-493 Ma (Vendian - Ordovician) were responsible for the generation of the Jaspa granite.

Trace element and REE distribution in allanite and monazite in Greater Himalayan rocks, Garhwal Himalaya

A detailed geochemical study has been carried out to understand the trace element and REE behavior in allanite and monazite in the Greater Himalayan rocks, Garhwal Himalaya. The total LREE content observed in allanite varies in a range of between ~0.282 - 0.522 atoms per 16 oxygen formula unit. The mineral is Ce-rich with a concentration in a range between 0.134 - 0.247 atoms. The other LREEs have concentrations in range of La (0.068 - 0.131 atoms), Nd (0.053 - 0.099 atoms), Pr (0.015 - 0.029 atoms), and Sm (0.011 - 0.018 atoms). Monazite has the nominal composition of LREE $(PO)_4$. The La, Ce, and Nd constitute more than 67% of the total cation proportion (excluding P), among which Ce is most abundant. Ce has a concentration in the range of 1.452 to 1.622 atoms per 16 oxygen formula unit. La and Nd contents are in the range between 1.235 - 1.605 and 0.561 - 0.735 atoms, respectively.

The trace elemental study shows that monazite is more LREE rich than the allanite. It is inferred from the mineral chemical study that allanite has undergone coupled substitutions $Ca^{2+} + Th^{4+} = 2REE^{3+}$ and $REE^{3+} + Fe^{2+} = Ca^{2+} + Al^{3+}$ whereas monazite chemistry indicates about brabantite and huttonite substitution.

TAT 1.5
Exhumation History of Higher Himalayan Crystallines of Zanskar, NW India

(Vikas Adlakha)

The southeastern region of the Higher Himalayan Crystalline (HHC) of Zanskar Himalaya characterizes a dome structure that is locally named as Gianbul Dome. This dome is extensional and is bounded by the South Tibetan Detachment System (STDS)/Zanskar Shear Zone (ZSZ) to the north and Chenab Normal Fault (CNF) to the south. This project aims to document the role of (a) normal faulting, i.e., extension along these faults, or (b) doming process, on the shallow crustal exhumation patterns the Gianbul Dome. New Apatite Fission Track (AFT) and Zircon Fission Track (ZFT) data have been obtained across the distal transect cutting across of the Gianbul Dome.

09 Apatite Fission Track (AFT) ages across the Gianbul Dome range from 5.9±0.5 to 11.7±1.8 Ma (Fig. 15 and 16a). The exhumation rates have been obtained using the 1D AGE2EDOT thermal model by utilizing these ages that range from 0.28-0.51 mm/yr at a mean rate of 0.40 mm/yr since ~19 Ma.

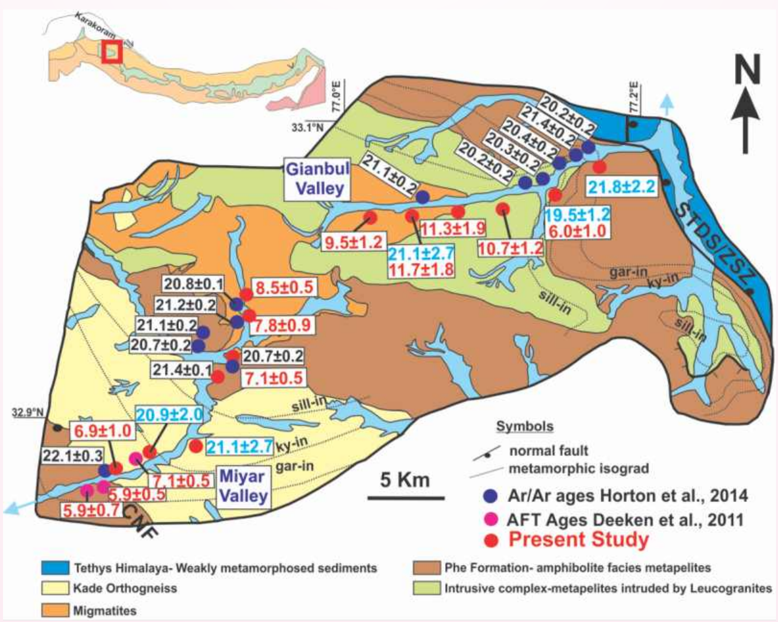

Fig. 15: Geological and Tectonic map showing the new AFT and ZFT ages obtained in the present study. AFT ages are in red font, ZFT ages are in cyan font. Red dots indicate the present study locations.

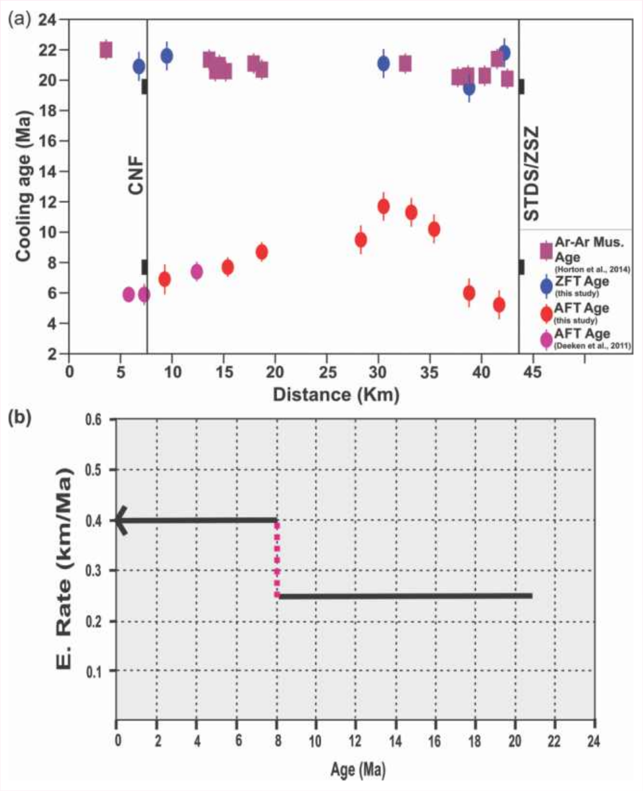

Fig. 16. (a) AFT and ZFT ages plotted with respect to CNF and ZSZ bounding the Gianbul Dome; (b) Plot showing the temporal variation in the exhumation rate of the Gianbul Dome. Note the increase in exhumation rate during Late Miocene.

Interestingly, the AFT ages show a young trend both towards the CNF to the south and STDS to the north. This younging of cooling ages suggests that STDS to the north and CNF to the south were active during ~6 Ma in this region and resulted in fast exhumation rates along these faults. Transient exhumation rates using the AFT and ZFT ages suggest that the dome exhumed at a rate of ~0.27 mm/yr during ~20.9-8.2 Ma for ~ thirteen million years. The rates were increased two times to 0.40 mm/yr since 8.2 Ma (Fig. 16b). The AFT and ZFT ages do not show any correlation with respect to the elevation (Fig. 17). This suggest that these ages are independent of topographic effect and variation in AFT ages are across the dome is solely controlled by normal faulting in the region.

The phase of ~20-8 Ma was the period of erosional exhumation. At ~8-6 Ma the CNF and ZSZ reactivated as normal fault. The latest phase since ~6 Ma was again a period of erosional exhumation of the dome. Thus, new AFT and ZFT region across the Gianbul dome of Zanskar Himalaya, NW India provide the first record of the re-activation of the CNF and STDS at ~6-8 Ma.

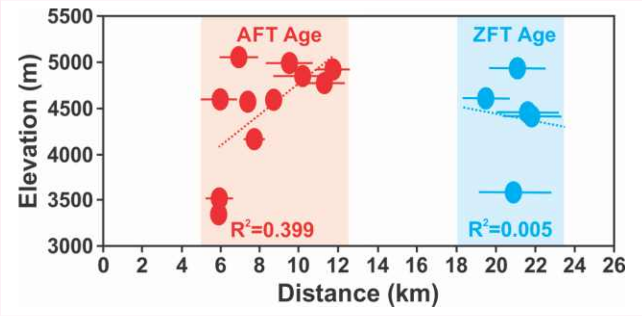

Fig. 17. Plot of AFT and ZFT ages obtained across the dome versus elevation.

TAT 1.6

Isotopic aquatic (major & trace elements) geochemistry and morpho-tectonic studies of geothermal systems (geothermal springs) of Kumaun West - Central Himalaya India: Implications for their source of origin and orogenic CO_2 degassing

(Sameer K. Tiwari, A.K.L. Asthana and Aditya Kharya)

Evaluation of geogenic carbon fluxes between solid Earth and its atmosphere is important to understand the global geological carbon cycle. The key geogenic CO_2 suppliers are the magmatic mantle and metamorphic degassing from active and quiescent volcanoes, fault zones, geothermal systems, and CO_2 rich groundwater. Indian Himalayan hosts about 340 geothermal springs in natural as well as the artesian condition that eject hot waters and volatiles with varied temperature and chemical composition. These sites provide an opportunity to analyze tectonically driven gas emissions and their impact on regional and global climate. In the present study, we adopt a method for direct measurement of Dissolved Inorganic Carbon (DIC ≈ HCO_3) concentration in the geothermal springs to estimate geogenic CO_2 flux from the active geothermal system (using water discharge of individual geothermal spring) between the tectonic boundaries of the Main Central Thrust (MCT) and Main Boundary Thrust (MBT) of the Kumaun west Central Himalaya, India.

In the study area (Fig.18), geothermal springs contain high $\delta^{13}C_{DIC}$ ratio (-3.4 ‰ to + 9.1‰ $_{VPDB}$), and among the major ions, bicarbonate (HCO_3^-) is major anion followed by sulfate, chloride, nitrate, and fluoride whereas calcium is the major cation followed by magnesium, sodium, and potassium in the collected samples. The elevated concentration of Cl^- and Ca^{+2} in these spring waters suggests affinity towards their deeper origin. These geothermal springs cover a large area of the Kumaun region showing a significant discharge of CO_2 in the atmosphere. Considering the widespread occurrences of geothermal springs in tectonically active areas worldwide, the proposed direct measurement of DIC may be used as a reliable tool to estimate CO_2 fluxes in different active orogenic settings within the Earth system. Results of stable isotopes of $\delta^{18}O_{(VSMOW)}$ and $\delta D_{(VSMOW)}$ in these geothermal spring waters follow the Global Meteoric Water Line (GMWL), suggesting affinity of their recharge through the meteoric origin.

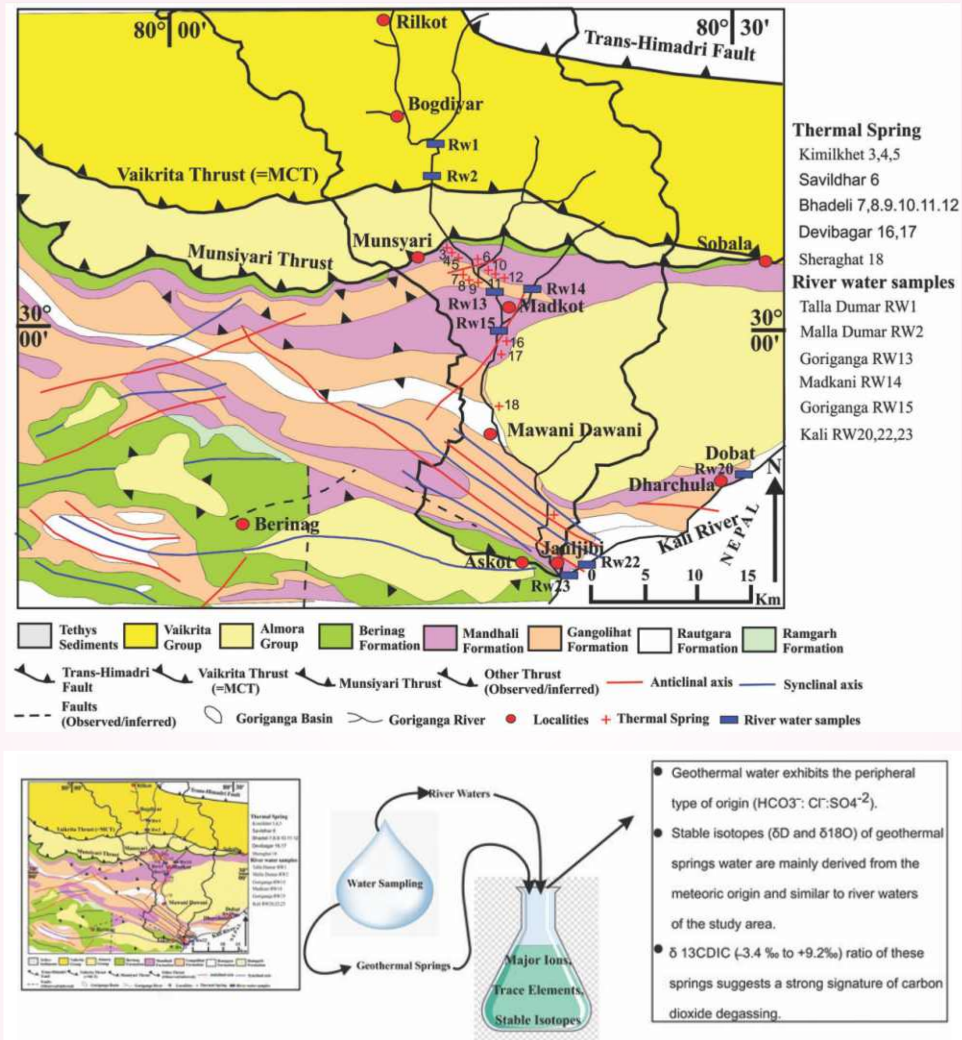

Fig. 18: Geological map of the study area with location (red filled circles) of studied geothermal springs.

TAT - 2: INDIAN MONSOON-TECTONIC INTERACTION AND EXHUMATION OF THE HIMALAYA

TAT- 2.1

Paleoclimatic records from Himalaya and its foreland and their hydrological impacts

(Pradeep Srivastava, Anil Kumar, Santosh K. Rai, Suman Lata Rawat, Jayendra Singh, Som Dutt, Prakasam M., Saurabh Singhal and Pinky Bisht)

This project produced data and understanding on fluvial, peat, lake, speleothem, past glaciations and tree ring records of Himalaya and its foreland.

Fluvial records

This year the work was carried out and summarized in Indus valley, Ladakh Himalaya and the Marginal part of the Ganga Foreland. The Ganga Foreland is a consequence of continent-continent collision and formation of the Himalayan thrust and fold belt. In the more distal part of the peripheral foreland basin, the Late Quaternary sedimentary architecture analysis from 17 stratigraphic successions together with optically stimulated luminescence dating (OSL) revealed interaction of peripheral bulge tectonics and climate over the past ~100 kyr. These sections exhibit three sedimentary packages formed under different environmental conditions. Detailed vertical and lateral sedimentary architecture delineates nine lithofacies that are grouped into three facies associations, (i) flood plain facies association, (ii) channel facies association, and (iii) interfluve facies association. The basal package-I, > 114 ka old, was deposited by sandy meandering channels and overlying to this with a hiatus of ~30 ka is package-II, ~80-54 ka, deposited by gravelly rivers. The sediments of both the packages-I, II are derived from rocks exposed in the peripheral bulge region. Overlain package- III, deposited by small meandering channels, consist of the sediments derived from the Himalaya. The results indicate that the duration of 80-54 ka was a period of forebulge uplift when gravelly fans prograded basin ward. Below the fan sediments lies a peripheral bulge unconformity marked by regionally significant pedogenic horizon. This pedogenic horizon qualifies as to be termed as peripheral bulge uncomformity. After 54 ka, the fine Himalayan sediments onlap the cratonic sediments implying rather a stable forebulge tectonics coupled with fluctuating climatic conditions, occasionally bringing micaceous gray coloured sand-silt of Himalayan origin.

In Indus the study, for the first time, attempted to constrain discharge during periods of established river aggradation and incision over late Quaternary. Here, geometric data from imbricated gravels of channel fills are used to calculate paleodischarges during net river aggradation at 47-23 ka, and preserved slack water deposits (SWDs) at 14-10 ka are used to constrain paleodischarges that occurred during net river incision. Catchment area-normalized discharge derived from these valley fill sequences ranges from 0.78 to 3.26 ($\times10^{-7}ms^{-1}$). Syn-incision discharge estimates yielded normalized discharge values of 6.17 ($\times10^{-7}ms^{-1}$) are considerably higher than discharges estimated from periods of aggradation. Morphometric analysis, chi slope, and Ksn, along the Indus River, observed no relation with the paleodischarge. This case study implies that net river incision in the upper Indus River occurs predominantly during relatively wetter climatic conditions than the climate during aggradation.

Peat and lake records

The 1.23 m thick sediment section was recovered from a wetland at Upshi located at the bank of the Miru River, a tributary to the Indus River, at Gya (N 33°42.240', E 77°42.194'; elevation ~4088 meter above sea level, m asl), Ladakh, northwestern Himalaya. The sedimentary archive from Upshi, northwest Himalayan region, provides a continuous vegetation and paleoenvironmental record of the last ~2700 cal. yrs BP. A detailed palynological, geochemical ($\delta^{13}C$, $\delta^{15}N$, TOC and TN) and environmental magnetic studies present a new paleovegetaion and paleoenvironmental dataset for the region. Pollen results show non-arboreal pollen (NAP) and non-pollen palynomorph (NPP) were dominant around Upshi from *ca.* 2646 to 2431 cal. yr BP, indicating a warm condition. The arboreal/ timberline forest and NAP in the study area gradually increased from *ca.* 2431 to 1860 cal. yr BP, under the prevalence of warm and wet conditions, corresponding to the Rowan warm period. This phase corresponds to rising $\delta^{15}N$ and χ lf. From *ca.* 1860 to 1154 cal. yr BP the increased Cheno/Am and substantial spread of NPP suggest decreased temperature and prevalence of cold-dry climate which is coinciding with to the declining trend of χ lf, $\delta^{15}N$, $\delta^{13}C$, TOC and TN. Since *ca.* 1154 to 293 cal. yr BP, the vegetation type reverses to mixed conifer and broadleaved forest with significant improvement of herbaceous taxa with rising $\delta^{15}N$, $\delta^{13}C_{org}$, TOC and TN suggesting warm and wet conditions in the study area. This period corresponds to the Medieval warm period. Amongst the proxies the highest sensitivity is observed in TOC and TN whose correlation with residual $\delta^{14}C$ shows Indian Summer Monsoon (ISM) is controlled by solar variability even in the rain shadow zone of the Himalaya. Cyclicities ranging from century to sub millennial scales controlled by solar changes are identified. $\delta^{13}C$, $\delta^{15}N$, aquatic pollens, grasses and sediment magnetic susceptibility appear to respond on millennial time scales.

Another record from Pindari basin produced a high resolution paleoclimate history using grain size and nitrogen isotope data. The result indicated; (1) stable and gradual climate amelioration during ~5300 to 3700 cal yr BP corresponded with early and mature Harappan civilization phase; (2) deteriorating climate recorded during ~3700 to 3230 cal yr BP corresponded with deurbanization phase of Harappan civilization; (3) strengthening ISM at ~3230 cal yr BP and abrupt centennial weakening of ISM at ~2300 cal yr BP coincided with beginning and end of Vedic Period in Indian subcontinent, respectively; (4) maximum deteriorated climate between ~1600 to 1100 cal yr BP (350-850 AD) broadly corresponds to Dark Age Cold Period (DACP); (5) strengthen ISM during ~1030 to 750 cal yr BP (920-1200 AD) corresponds to global Medieval Climate Anomaly (MCA); and (6) weakening of ISM during ~500 to 330 cal yr BP (1450-1620 AD) corresponds to global cold-dry Little Ice Age (LIA) event. Since, 330 cal yr BP, summer monsoon improved similar to present day.

Third study involved Lake Pangong Tso which is situated in eastern Ladakh with a catchment area of about 2000 km^2 with its aerial extent being around 650 km^2 with the maximum width of the lake being ~8 km on the Indian side but an average width of ~ 3 km. Pangong Tso is a brackish water lake that lies along Pangong strand of the Karakoram strike slip fault in arid Trans Himalayan region. The geomorphic mapping along the periphery of the lake suggested presence of four paleolake level strands located at 6 m, 4.8 m, 3.8 m and 1.25 m above the present lake level. The gullied periphery expose relict deltaic sediments where sedimentological study enabled us identify four deltaic lobes that make a classic Gilbert-type delta with well-developed top-set, fore-set and bottom-set. The top-set of the stratigraphyically oldest delta lobe that corresponds to highest lake level shows presence of freshwater molluscs identified as *Radix* and a burnt sediment layer (hearth). The charcoal derived from this layer yielded ^{14}C date as 1.7 ka BP and six luminescence ages from different delta lobes suggested that delta evolution and lake level fall of ~6 m took place between ~2-1 ka. Review of paleoclimate record available from NW Himalaya and Pangong Tso suggests late Holocene aridity might be responsible for this rapid lake level fall. Sclerchronological analysis carried out on 54 sub-samples from three *Radix* specimen suggested modern type of seasonal conditions may have prevailed at ~1.7 ka BP.

Paleoglaciation

Two tributary glacial valleys were investigated in the upper Kali Ganga valley, Tethyan Himalaya, for the study of the palaeo glacial reconstruction. We observed multiple sets of lateral moraines preserved in two tributary glacier valleys. The catchment is an ideal region for studying the Quaternary glacial history because it is situated in the transitional zone of two major climatic systems *i.e.* summer monsoon and westerlies and have well-preserved glacial deposits, extending from the outermost moraines to the most spatially restricted retreat phases. However, no previous work has been conducted to constrain the glacial chronology in this area. To develop a framework for geomorphic and paleo-glaciation studies in this region, we examined the glacial moraine and other paraglacial landforms and determine the extent and timing of past glaciation using field mapping, remote sensing and by dating glacial landforms using Optical Stimulated Luminescence (OSL) dating methods. 12 OSL ages from the glacial moraines of two tributary glaciers allowed us to conclude that the valley has preserved four events of glaciation. The glacier advances in this region have taken place during the MIS-4/3, MIS-2, Younger Dryas and Mid Holocene. These events coincide well with the cold and dry phase of the climate system. The overall pattern of glaciation across the valley suggests that the low temperature and changes in the precipitation brought by westerlies may be the major reason influencing the timing and the extent of the glaciation during the last glaciation.

Dendrochronology

Tree ring-width chronologies, the longest covering last millennia, of *Cedrus deodara* were developed from moisture stressed sites of Gangotri region, Garhwal Himalaya. Tree-growth climate analyses of these chronologies revealed significant positive relationship with winter and spring precipitation. Climatic signal inferred in the chronologies were further used to develop climate record for the last ~900 years. Long-term high-resolution climate record capturing low frequency variations is longest so far from the Garhwal Himalayan region. Further, successfully dated *Betula* *utilis* cores collected from Dokriani glacier forefield and developed ring-width chronology extending back to AD 1710. Ring-width chronology revealed influence of summer temperature on growth of trees in the region.

Speleothem record

A high resolution oxygen isotopes record of speleothem from the Wah Shikar cave, Meghalaya, northeastern India suggests that several sudden fluctuations in summer monsoon precipitation during the last ~900 yrs. The intervals of Medieval Climate Anomaly (MCA) and the Current Warm Period (CWP) witnessed strengthened Indian summer monsoon (ISM) whereas multiple shifts occurred during the Little Ice Age (LIA). The abrupt precipitation shifts were more frequent during the warmer intervals than the LIA with a secular trend with few exceptions. Changes in atmospheric temperature due to volcanic eruptions and sun spot activity have played major role in the onset of the LIA and other prolonged weak intervals of the ISM during the last ~900 yrs.

Another record from the Mawmluh cave, Meghalaya show general enrichment in the oxygen isotope ratios suggesting declining summer monsoon precipitation during the period of speleothem growth. Interestingly, the variability in the carbon isotopes was higher than the oxygen isotopes (Fig. 19). A speleothem record of Indian summer monsoon variability from northwest Himalaya suggest dry climate during 309 to 291 Kyr BP and 287 to 264 Kyr BP, and strong summer monsoon from 291 to 287 Kyr BP and 264 to 261 Kyr BP, controlled by the sea surface in conditions in the North Atlantic and northern hemisphere summer insolation.

TAT -2.2

Aquatic geochemistry and morpho-tectonic studies in the Indus River system: Implications to denudation process and evolution of land forms in the Northwest Indian Himalaya

(Santosh K. Rai and A.K.L. Asthana)

Geochemical results [HCO_3+SO_4 vs Ca+Mg] from the Indus River system show that the alkalinity in these waters may be sourced from the Silicate weathering. A part of such weathering could be routed through the H_2SO_4 and hence it does not consumes any CO_2 from the atmosphere.

The stable isotopes ($\delta^{18}O$ & δD) in the time series samples of the Himalayan Snow suggests about the multiple sources of moisture (other than westerlies) contributing to the precipitation in the Northwest Himalaya. The stable isotopes ($\delta^{18}O$ & δD) in the time series samples of the Himalayan Snow (Fig. 20) from the Indus catchment suggest the multiple sources of moisture (other than westerlies) contributing to the precipitation in the Northwest Himalaya.

Strong variation in the *d-excess* (= $\delta D - 8*\delta^{18}O$) values (33-7) appears to be linked with the mixing of

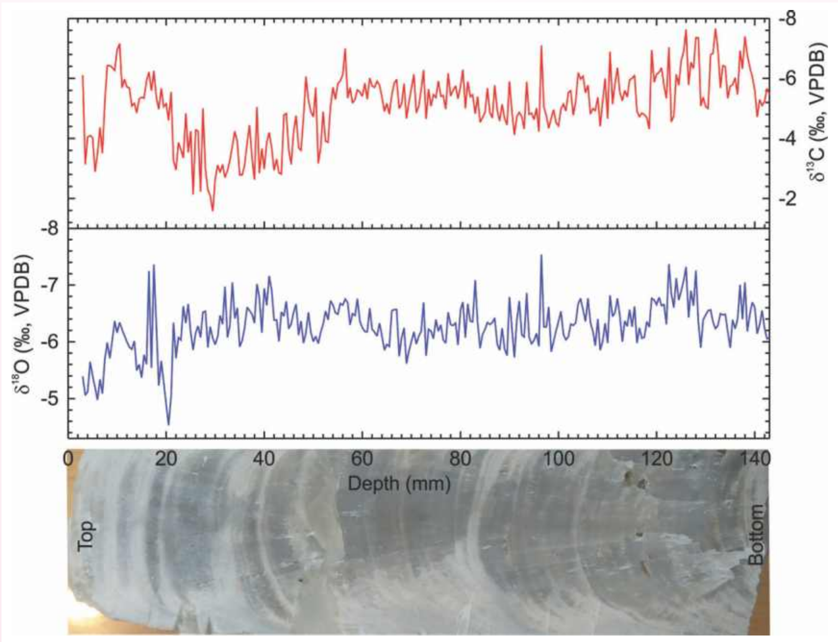

Fig. 19: Stable oxygen isotopes record for Indian summer monsoon variability from the Mawmluh cave, Meghalaya, northeast India

TAT - 2: INDIAN MONSOON-TECTONIC INTERACTION AND EXHUMATION OF THE HIMALAYA

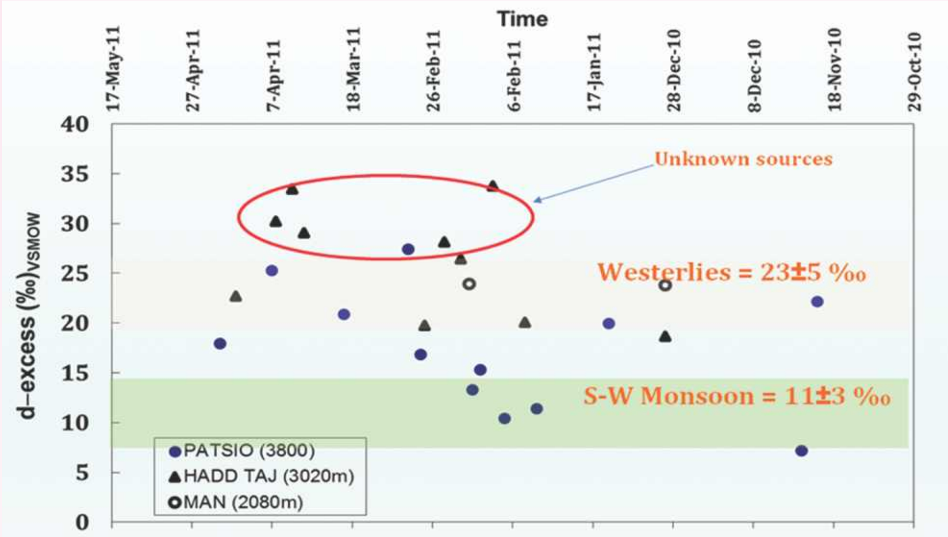

Fig. 20: The d-excess (= δD- 8*δ^{18}O) in the time series snow samples indicating an unidentified source of moisture in the Indus catchment.

multiple sources of moisture contributing to the annual precipitation in the Indus catchment covering the Northwest Himalaya. Towards this, the High d-excess may represent the dry Climate with high evaporation. This shows that the variation in the snow samples may not be explained only with the moisture source from westerlies and south west monsoon and hence the other local source(s) may be required. In addition, the laboratory based fractionation studies were also made to use the isotopic composition (δ^{18}O) to estimate the ground water temperature.

The Beas, a tributary of Indus River, covers the altitudes of 3800m (Rohtang) to 1000m and drains an area of ~1350 km^2 in its upper reaches. It has slope varying from 15^0 to 45^0 which is mainly regulated by local geology and erosional cycles. The main stream length ratio of the basin is ~15 km indicates that the study area is elongated with moderate relief and steep slopes. Morphometric parameters enables to divide the basin into six major altitudinal regions contains the distribution of area under different altitudinal zones which are helpful in regional planning for development.

TAT 2.3

Past 2 ka climatic variability in Himalaya using multiproxy and multi-archival records

(Narender K. Meena, Sudipta Sarkar and M. Prakasam)

Past 2K climate records from Chitkul, Sangla (Baspa Velly) and Chakrata Peat profiles

For the past 2K paleoclimatic study in the NW Himalaya, we selected the peat deposits along the Baspa valley, Kinnaur, Himachal Pradesh and a meadow litho-section around Koti-Kanasar village, Chakrata and Uttarakhand area (Fig. 21). The peat deposit of Kinnaur (31.3517°N, 78.4175°E & 31.3477°N, 78.4664°E) and a meadow litho-section of Chakrata (30.77°N, 77.83°E) are located at altitudes of ~3450 and ~648 meters above mean sea level (AMSL), respectively, in the northwest Himalaya. The multi-proxy data *i.e.* diatoms, environment magnetism, stable isotopes, and total organic carbon (TOC) has been generated for collected samples. The chronology of the sampled section is

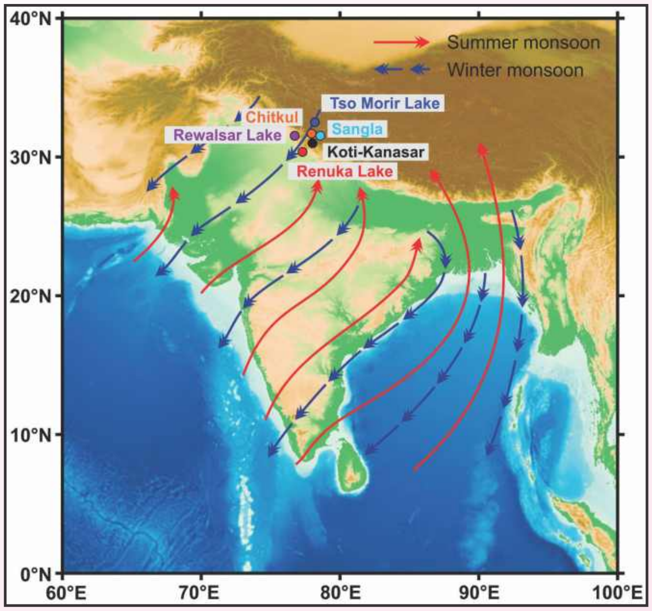

Fig. 21: Location map of the studied NW Himalayan Lakes with monsoonal wind directions.

TAT - 2: INDIAN MONSOON-TECTONIC INTERACTION AND EXHUMATION OF THE HIMALAYA established using the AMS ^{14}C dating technique. High-resolution multi-proxy analysis from these archives provides the remarkable insights into monsoon variability on annual to millennial scales that helped to assess the response of monsoon to different forcing factors. These sections used to reconstruct the modern to 10936±41 B.P. climatic records. The environmental magnetic (χlf) data shows the variation in magnetic mineral concentrations due to the physical and chemical weathering. The total organic carbon (TOC) values ranging from 0.32 to 22.87 (wt. %) with an average value of 3.97 (wt. %). The results of TOC concentration shows the productivity of the area. The diatoms are predominantly useful for climate studies as they are sensitive to different conditions i.e. warm and cold climate. Diatoms genera have found in the Kinnaur area, which is mostly freshwater, glacial to the non-glacial origin with low to high alkalinity.

TAT 2.4

Black Carbon monitoring in north-west Himalaya

(P.S. Negi and Chhavi P. Pandey)

In order to monitor ambient Black Carbon (BC) concertation in Alpine Ecosystem, especially in Gangotri Glacier Valley (GGV), BC monitoring stations are already established near to Gangotri Glacier at Bhojbasa (3800 m asl) and Chirbasa (3600 m asl). Eighteen days field work has been conducted to collect data from the instrument and to understand potential source of BC origin and its seasonal variability besides its potential interlinkage with regional meteorology and ground conditions including natural as well as anthropogenic factors. Due to inhospitable working conditions, baseline data on BC is hardly available from most of the glaciated Himalayan region except this work that provides the first real-time and all-weather measurement of ambient BC mass concentration near Gangotri Glacier which is one of the largest glaciers in Indian Himalayan cryosphere. After correction, processing and analysis of data collected earlier, significant variation in the BC concentration over the observation site has been observed from 0.01µg/m^3 to 4.62µg/m^3 for Chirbasa sitedata processed during the year 2019. The diurnal variation ranges from 0.1µg/m^3 to 1.8µg/m^3. The monthly mean concentration of BC varies from a minimum of 0.087±0.046 µg/m^3 in August to a maximum of 0.823 ± 0.711 µg/m^3 in May. The monthly and seasonal variation in BC mass concentration is depicted below in figure 22. These observations are published in Atmospheric Environment during the year 2019. Being a pristine locality, the observed BC concentration is far below from the Indian and global limit of the respirable pollutants, i.e. 60 µg/m^3 and 25 µg/m^3. However, observed BC concentration is likely to change the radiation budget that onwards influences ecosystem characteristics and associated natural resources. The analysis of HYSPLIT backward air-mass trajectories and the active fire spots distribution from the MODIS, meteorological data and ground survey indicated that seasonal cycle of BC was significantly influenced by prevailing meteorological conditions and the continental (Mediterranean region) as well as the long-range, short-range transport (Indo-Gangetic plain) of BC coupled with emission at local scale due to burning of biomass (forest-firewood) and fossil fuel. Besides overall concentration of the black carbon (BC), the composition of fossil fuel (BC_{ff}) and wood biomass (BC_{wb}) also have been detected and shown in (Fig. 22) jointly.

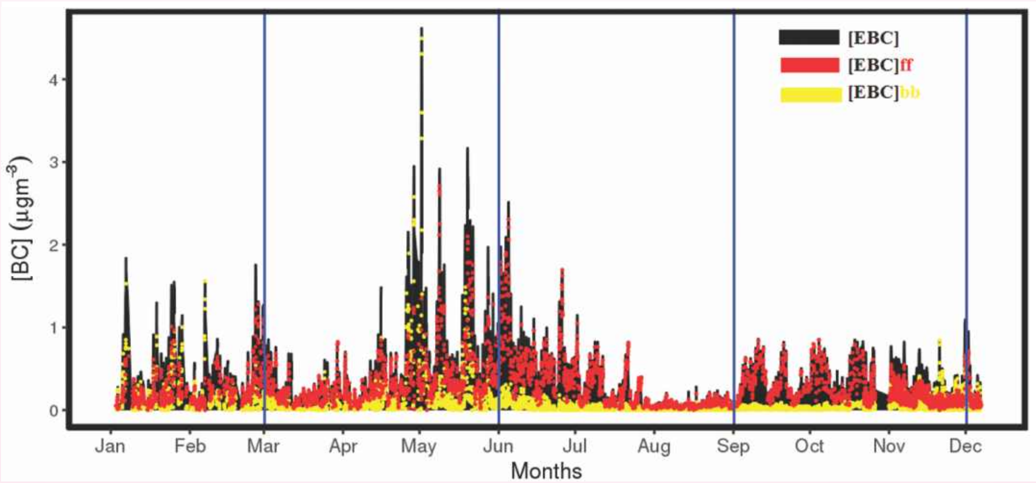

Fig. 22: Near real-time recording of BC along Gangotri Glacier Valley. Red dots indicate fraction of BC due to fossil fuel and yellow dots depicts fraction due to biomass burning whereas black colour indicate combined black carbon recording.

In addition to the real time and all weather data observed and depicted in figure 22, random BC data also has been collected with the help of handheld Aethalometer (Model AE 51) along the Gangotri Glacier Valley (GGV) at five different sites viz Gangotri (~3200 m amsl), Chirbasa (~3600 m amsl), Bhojbasa (~3900 m amsl), Gaumukh (~4000 m amsl) and Tapovan (~4400 m amsl) during 2015-2019. The altitudinal variation in BC concentration over these five sites along GGV is shown in figure 23. It is discernible from the figure 23 that BC concentration decreases with increasing elevation with slight increase at Tapoban that may be attributed to the local anthropogenic influence.

Apart from black carbon particles, other aerosols also affect the Earths radiation budget in various ways by interacting with the incoming solar radiation. The pristine location of Gangotri Glacier Valley can provide an ideal place for studying the natural aerosol composition, especially elemental composition such as presence of C, Na, Al, Si, K, and Ca etc. obtained from (Energy Dispersive Spectroscope) EDS. The physio-chemical properties viz. morphological parameter and composition at individual particle level are important inputs to the optical model for assessing the optical sensitivity towards said properties. Using in-house facility at WIHG (SEM-EDS) we have taken 12 SEM images of quartz filter tape of Aethalometer (AE33) installed at Chirbasa (Fig. 24). The further analysis of SEM images is in progress to understand physio-chemical properties of aerosol particles.

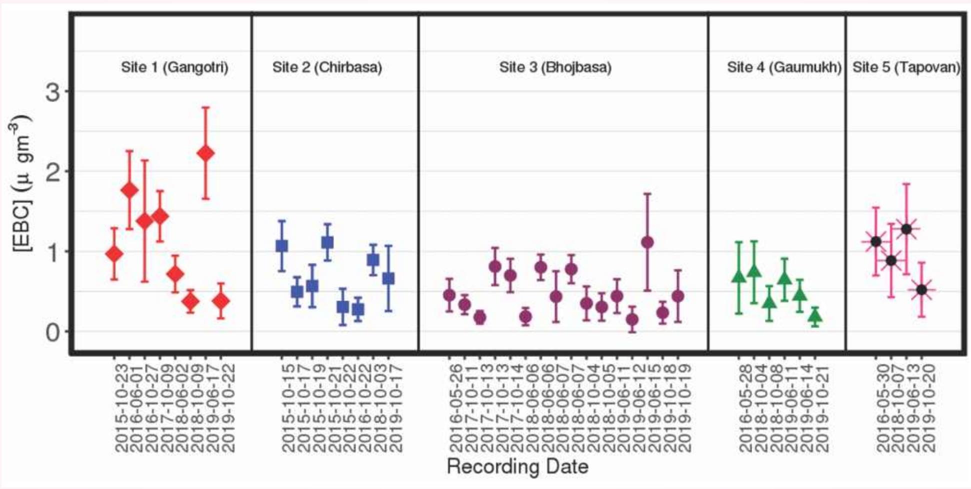

Fig. 23: Multi-year random observations of BC along Gangotri- Gaumukh -Tapoban trek during summer and winter season. For this pilot expeditions program five observing sites at different altitude were selected (viz. Gangotri, Chirbasa, Bhojbasa, Gaumukh and Tapovan respectively).

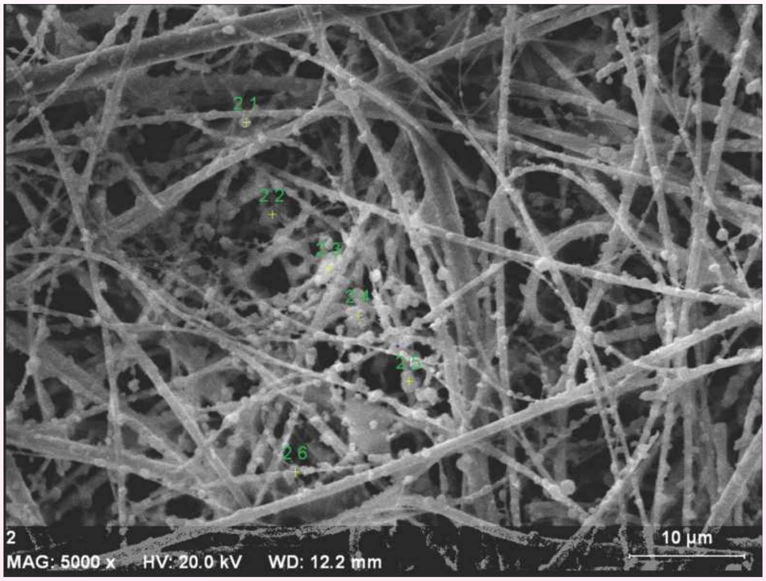

Fig. 24: SEM image of aerosol particles deposited on quartz filter tape of Aethalometer AE 33.

TAT 2.5

Late Quaternary summer monsoon variability and its connection with erosion in the western Himalaya from Site U1457, Arabian Sea

(Anil Kumar and Som Dutt)

The intensity of turbidities sedimentation over long time scales is driven by sea-level changes, tectonically driven rock uplift and climatically modulated sediment delivery rates. This study focuses on understanding the effect of sea-level fluctuations and climatic variability on grain size variations in the Arabian Sea. The grain size and environmental magnetic parameters of Arabian Sea sediments have been documented using 203 samples, spanning the last 200 kyr, obtained from International Ocean Discovery Program (IODP) Site U1457 (Fig. 25). Grain size end member modelling suggests that a high coarse silt fraction between ~200 and 130 ka than the period after, caused by sediment transport following reworking of the Indus Fan and development of deep sea canyons. The sediment size and high magnetic susceptibility indicate a dominant flux of terrestrial sediments. Sedimentation in the distal Indus Fan at ~200-130 ka, was driven by a drop in sea-level that lowered the base level in the Indus and Narmada river systems. The low sea-stand caused incision in the Indus delta, canyons and fan area, which resulted in the transportation of coarser sediment at the drilling site. Globally, sea-level fell during ~200-130 ka suggesting ice-volume increase in the northern hemisphere. The falling base level would have driven incision and an increase in the coarse silt fraction into the deep water. The augmentation in coarse silt and EM3 implies sediment transport by erosion of the delta and shelf areas, as well as the Indus canyon. Five erosive channels in the vicinity of the Site U1457 and three major canyons along the middle Indus Fan margins imaged by a GLORIA sidescan sonar survey have been identified (Fig. 25). These canyons were perhaps active and may have transported the coarse silt towards Site U1457 between ~200 and 130 ka. Magnetic susceptibility and other associated magnetic parameters suggest a large fraction of the sediment was supplied by the Narmada River during ~2001-30 ka. Since ~130 ka, clay-dominated sedimentation is attributed to the rise in sea-level due warm and wet climate.

$\delta^{13}C_{SOM}$ in sedimentary organic matter (SOM) highlighted the relative contribution C3 and C4 plants to the Site U1457, Arabian Sea. Significantly lower $\delta^{13}C_{SOM}$ values (c. −24.0‰) ~8-7 Ma suggest a high input of C3 terrestrial organic matter. The increase in $\delta^{13}C_{SOM}$ values during ~7 to ~2 Ma indicates that C4 biomass overwhelmed the terrestrial catchment environment as a result of enhanced terrestrial aridity in the Himalayan foreland.

A giant mass transport complex was recently discovered in the eastern Arabian Sea, exceeding in volume all but one other known complex on passive

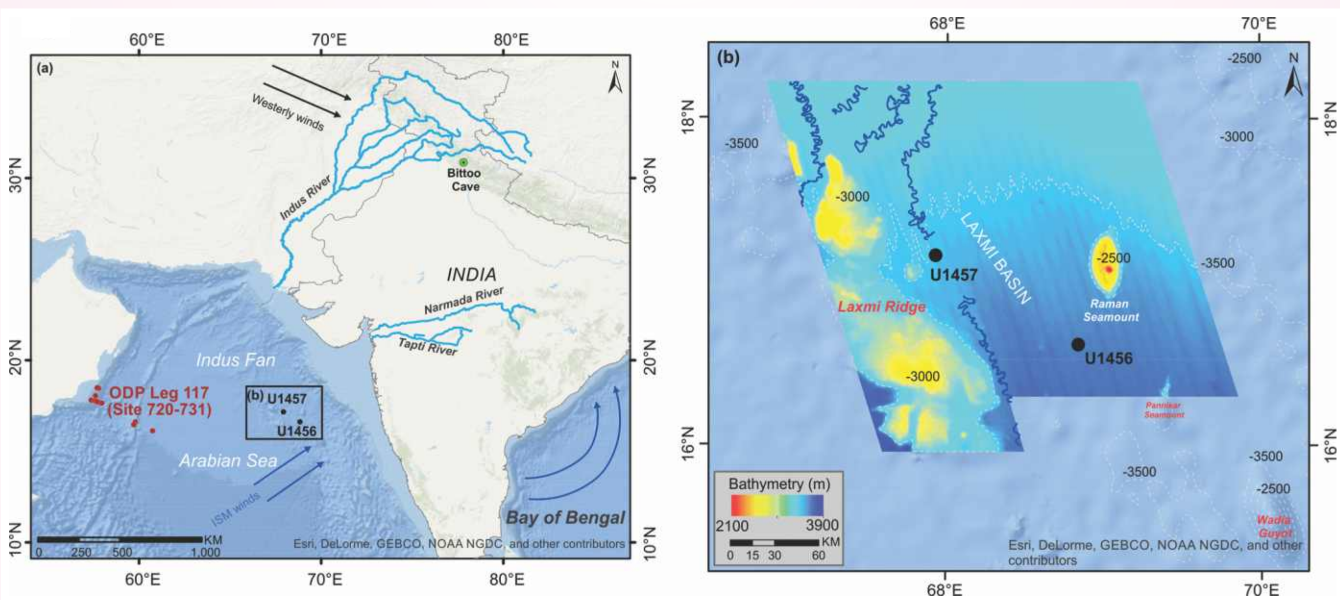

Fig. 25: (a) Map showing location of the IODP Sites U1456 and U1457 in the eastern Arabian Sea overlain on a regional bathymetric map. Course of the major river systems draining to the Arabian Sea are also displayed. (b) An enhanced bathymetric grid (after Prerna et al. 2015) of the rectangular block shown in (a) with a number of active channels surrounding drill sites.

margins worldwide. The complex, named as the Nataraja Slide, was drilled by International Ocean Discovery Program (IODP) Expedition 355 in two locations where it is ~300 m (Site U1456) and ~200 m thick (Site U1457). The top is defined by the presence of both reworked microfossil assemblages and deformation structures, such as folding and faulting. The deposit consists of two main phases of mass wasting, each which consists of smaller pulses, with generally fining-upward cycles, all emplaced just prior to 10.8 Ma. The base of the deposit at each site is composed largely of matrix-supported carbonate breccia that is interpreted as the product of debris flows. In the first phase, these breccias alternate with very well-sorted calcarenites deposited from a high energy current, coherent limestone blocks that are derived directly from the Indian continental margin, and few clastic mudstone beds. At the top of the deposit, in the second phase, muddy turbidite deposits dominate and are increasingly more siliciclastic. At Site U1456, where both phases are seen, a 20 m section of hemipelagic mudstone is present, overlain by a ~40 m thick section of calcarenite and slumped interbedded mud and siltstone. Bulk sediment geochemistry, clay mineralogy, isotope analysis, and detrital zircon U-Pb ages constrain the provenance of the clastic, muddy material to being reworked Indus-derived sediment, with some input from smaller western Indian rivers (e.g., Narmada and Tapti Rivers), and some material from the Deccan Traps. The carbonate is a shallow-water limestone from the outer western Indian continental shelf that was likely oversteepened from enhanced clastic sediment delivery during the mid-Miocene. The final emplacement of the material was likely related to seismicity as there is evidence for intraplate earthquakes close to the source. Although we hypothesize this area is at low risk of future mass wasting events, it should be noted that other continental margins around the world could be at risk for mass failure as large as the Nataraja Slide.

TAT - 3: EARTHQUAKE PRECURSORS STUDIES AND GEO HAZARD EVALUATION

TAT 3.1

Seismological, seismotectonic and subsurface related studies and hazard evaluation from the NW Himalaya, Ladakh & Jammu & Kashmir regions

(Sushil Kumar, Ajay Paul, P.K.R. Gautam, Narendar Kumar, Chhavi P. Pandey and Parveen Kumar)

Crustal structure, stress field evolution across NW Himalaya, India from a combined seismic and gravity study

The new seismic data recorded with the Wadia Institute of Himalayan Geology (WIHG) seismic stations along a NE-SW profile in NW Himalaya, India are combined with the pre-existing data from other catalogues and jointly inverted with the global gravity data to delineate the crustal structure and stress fields in this part of Himalaya. Modelling of gravity data, constrained from seismic results (Fig. 26), suggests that long wavelength gravity anomalies arise due to variations in the depth of Moho (35 to 80km), which are caused by flexed lithosphere of effective elastic thickness of ~53 km. This effective elastic thickness of ~53 km, comparable to the focal depths of the earthquakes, suggests that the whole crust is seismogenic and brittle. The gravity modelling resulted in presence of subsequent high density within the low density between the MCT and STD, which can be attributed to the presence of extended surface structures into the subsurface. The reported low density in the region towards the western side of the Kaurik-Chango Fault of the Tethys Himalaya (TH) may have been resulted due to the soft-sediment deformation taking place within different lacustrine

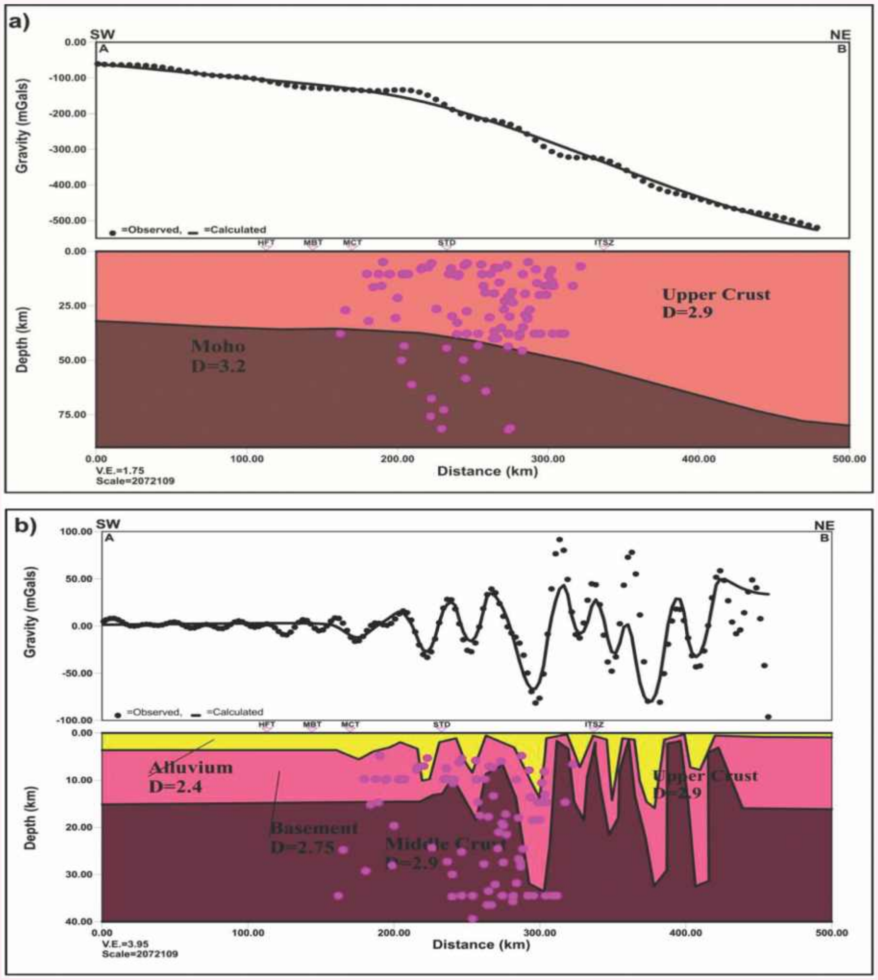

Fig. 26: Observed and calculated response from gravity data and the corresponding lithospheric model (Bottom) for NW Himalaya (a) Regional and (b) Residual.

sedimentary bodies present. We also analysed the stress fields acting in the NW Himalaya, India by inverting the *P*- and *T*-axes of the focal mechanisms obtained. P-axes and the maximum horizontal compressive stress $\sigma 1$ axis are predominantly NE-SW oriented for the Sub-Himalaya (SH), Lesser Himalaya (LH) and Higher Himalaya (HH), whereas it's N-S with an E-W extension for Tethys Himalaya (TH). This difference in the stress field across major tectonic units of NW Himalaya can be attributed to the strain and stress partitioning during oblique convergence.

Coulomb stress modelling and seismicity in the western Himalaya, India since 1905: Implications for the incomplete ruptures of the Main Himalayan Thrust

Coulomb failure stress transfers due to major past earthquakes reactivated the detachment thrusts in western Himalaya. Rupture geometry is controlled by dip angle of the Main Himalayan Thrust. Past moderate to large earthquakes contributed to the existing strain budget in the western Himalaya for the past 109 years. The along-strike terminations of seismic ruptures on the Main Himalayan Thrust (MHT) due to four earthquakes of magnitude (Mw) $\geq$ 6.6 in the period 1905-2019 is investigated in terms of Coulomb stress evolution. It is established that the absence of surface expressions of earthquake ruptures on the detachment is due to the presence of heterogeneous patches of fossil strain. This seems to be reliant on the width of the interseismic decoupling transition zone, which depends on the local dip and depth of the decollement as indicated by our Coulomb stress modeling. This study highlights the fact that the upper part of the MHT plane is locked and accumulates more strain and only slips during a great earthquake as compared to the lower part, which creeps steadily beneath the Eurasian plate and slips aseismically producing microearthquakes during the interseismic period. The positive Coulomb stress (Fig. 27 and 28) on the detachment in this western Himalayan segment is consistent with tectonic loading over at least

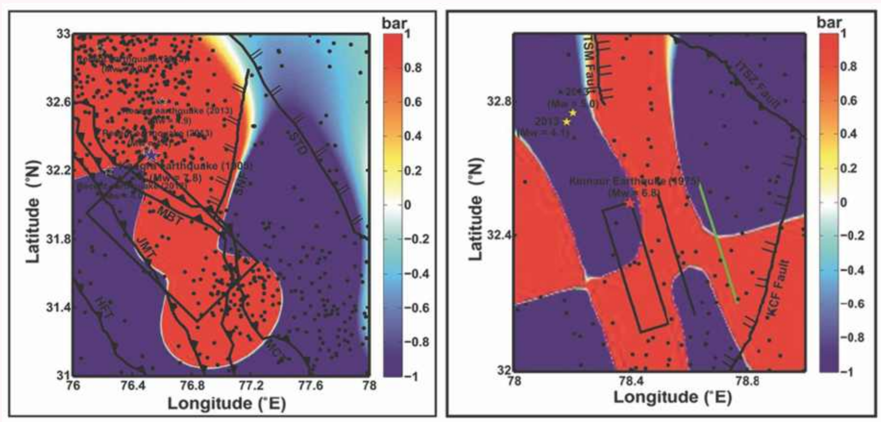

Fig. 27: Static stress change and present hazard scenario in the source zone of 1905 Kangra earthquake with MHT as the receiver fault. Static stress change and present hazard scenario in the source zone of 1975 Kinnaur earthquake with Kaurik as the receiver fault.

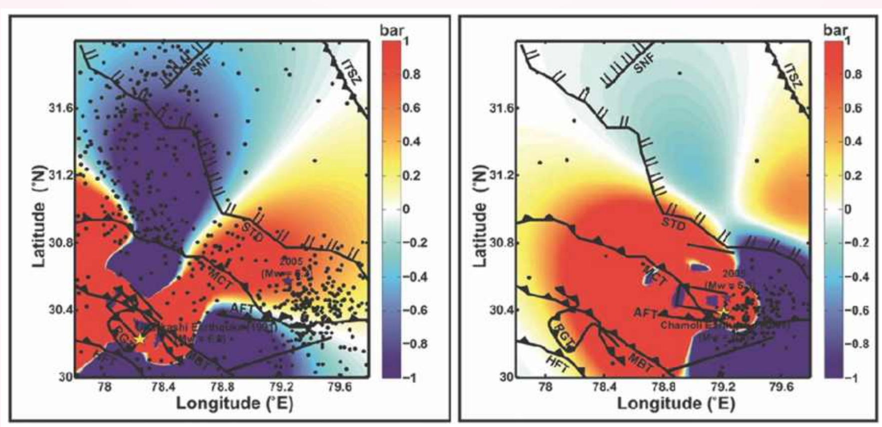

Fig. 28: Static stress change and present hazard scenario in the source zone of 1991 Uttarkashi earthquake, having MBT as the receiver fault; Static stress change and present hazard scenario in the source zone of 1999 Chamoli earthquake MCT as the receiver fault.

the past 100 yr., which we expect will lead to future earthquakes and associated seismic hazard in the western Himalaya.

Study of the Present and Historical Earthquakes triggered in in the Garhwal Himalaya which lies in the Central Seismic Gap to understand their seismotectonic implications

The use of micro-seismicity to study the spatio-temporal variations for delineating the seismogenesis and seismotectonics is a difficult task to perform, but an essential one for the seismically active regions, like the Garhwal Himalaya. Here, we present a well located earthquake catalogue of magnitudes 0.6≤M≤5.0, recorded for eight and half years for the Garhwal Himalaya by a seismicity monitoring network operated by Wadia Institute of Himalayan Geology, Dehradun in India (Fig. 29). These events are relocated using a double-difference algorithm by Waldhauser and Ellsworth (2000). Additionally, a historical seismicity catalogue of M≥4.0 for the last 22 decades has been compiled.

These catalogues are then used to study spatio-temporal variations of seismicity in this region using Fractal dimensions (Dc-value) and b-values to derive the seismotectonics and stress conditions in the region. The Dc-value estimated from the present seismicity is 1.47 for this region, which suggests the heterogeneity of the region, possibly due to the deep rooted transverse structures, like the Delhi Haridwar Ridge and the presence of local faults (Fig. 30). The b-values estimated to be 0.70±0.06 and 0.87±0.09 from the present and historical seismicity catalogs, respectively (Fig. 30). The low b-value suggests the high stress accumulation in this region of the Himalaya. The comparison between these two parameters (b-value and Dc value) suggests a positive correlation with the similar trend from the results of present study as well as from the previous studies.

The seismic cross sections along three arc-normal profiles across the three zones (viz., NW, Central and SE) have been drawn with the relocated micro-seismicity, tectonic features and their depth traverses along with the moment tensor solutions, reproduced from Prasath et al. (2017). The epicentral locations of the relocated micro-seismicity follow the trend of the HSB; this includes four major clusters, out of which three clusters are located in and around the MCT zone.

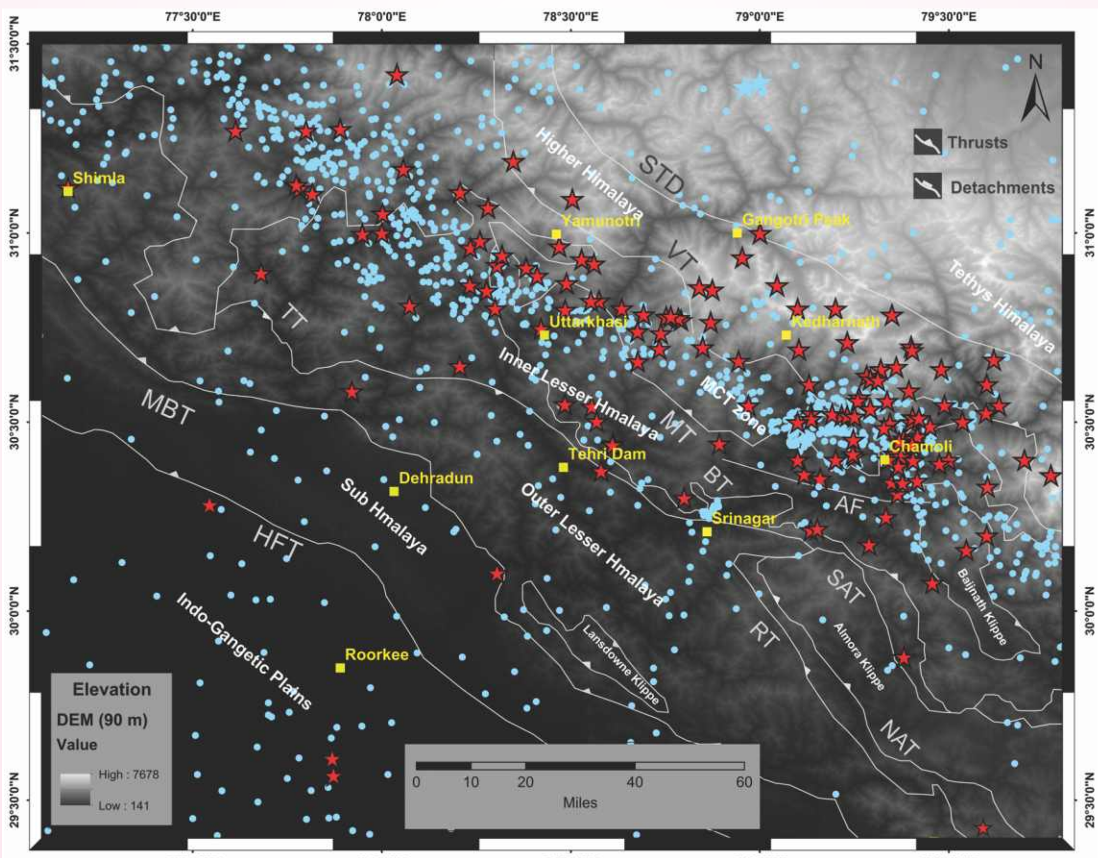

Fig. 29: Geology, tectonics and seismicity of the Garhwal Himalaya.

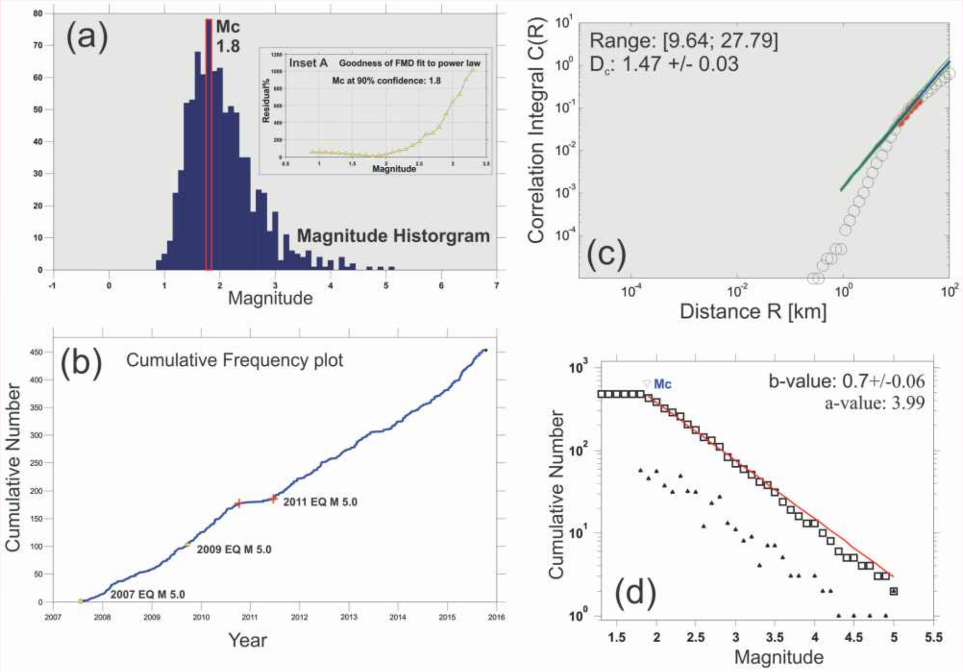

Fig. 30: Results of the Spatio-temporal analyses of seismicity between 2007 and 2015 with Magnitude completeness MC = 1.8

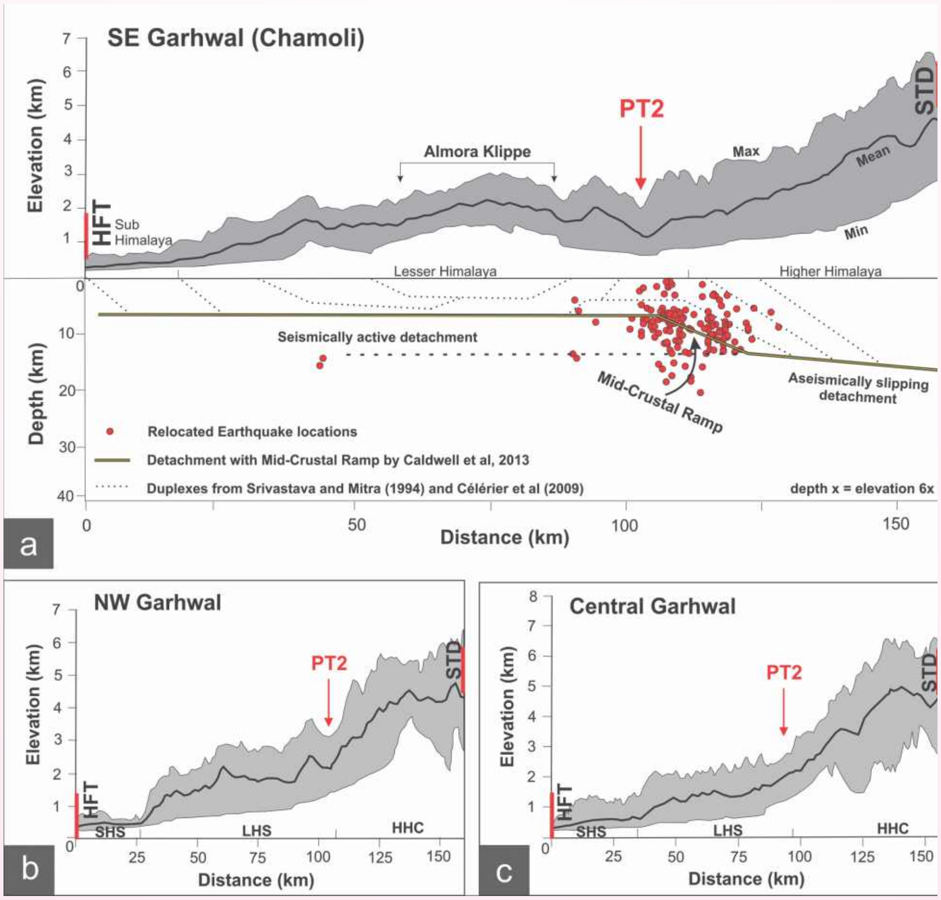

Fig. 31: Shows the swaths of Maximum, Minimum and Mean elevation.

TAT - 3: EARTHQUAKE PRECURSORS STUDIES AND GEO HAZARD EVALUATION

The hypocentral locations of these relocated earthquakes are confined to the depths between 5 and 17 km; around the MCR of the MHT, which is located at the depths around 8 and 15 km.

The seismic cross sections and elevation swath profiles with sharp Physiographic transition above the mid-crustal ramp structure in all three sections indicate the constant presence of the Mid- Crustal Ramp in the detachment plane and its active seismogenic nature (Fig. 31). The high fractal dimension and low b- value (0.70) suggest high stress accumulation and high probability of future large earthquakes in this region. Further, we report a quiescence period after the Chamoli earthquake of M 5.0 in 2011 and an increased stress level and increased seismic activity in the Chamoli region. The recent earthquakes, which include the M 5.3 Chamoli earthquake in 2017 also supports this claim of increased seismic activity. The study further suggests high possibility of large earthquakes in this region and recommends detailed seismic hazard evaluation in and around Chamoli region.

Seismically induced snow avalanches at Nubra-Shyok region of Western Himalaya, India

Snow avalanche can be triggered by different mechanisms including metrological conditions, snow pack stability together with external factor such as seismic tremor, explosions etc. The snow avalanche triggered by seismic event is very important hazard phenomena in the snow covered region. In this work, investigation of earthquake induced snow avalanches is introduced in Nubra-Shyok region of Western Himalaya, India. Compilation of seismogenic snow avalanche and earthquakes occurred in the Nubra-Shyok region during the period of 2010-2012 is made, which reveal that out of 393 natural avalanche, 81 avalanches was triggered due to the earthquake during this period and shown in figure 32. The local earthquakes occurred in Nubra-Shyok region, recorded by a local seismic network is utilized for this work. The same date of occurrence of earthquakes and snow avalanches confirm seismogenic snow avalanche in this region.

In the present work, avalanches triggered due to natural seismicity during the period of 2010-2012 related with earthquakes of magnitude 1.7≤ Mw ≤ 4.4 and distance of induced snow avalanche from epicenter of earthquakes i.e. 4 - 92 km are considered. In this study, lower bound limits of earthquake magnitudes, which cause avalanches, are established up to the distance of 92 km. Relation between earthquake magnitude and distance of induced snow avalanche from epicenter reveal that an earthquake of magnitude

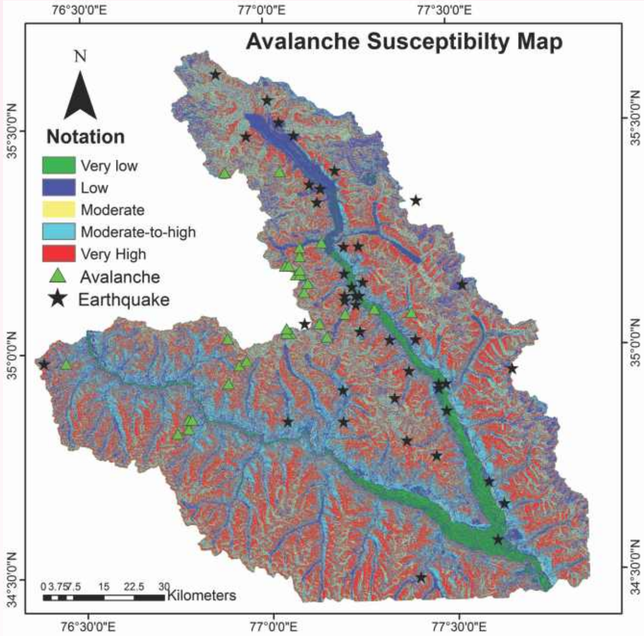

Fig. 32: Seismogenic avalanche and epicenter of earthquakes on the avalanche susceptibility map of region. Different colors represent different avalanche susceptibility zone (Modified after Parsad et. al, 2017).

1.4 (Mw) can trigger a snow avalanche as distance approaches to zero from earthquake epicenter.

TAT - 3.2

Seismotectonics and subsurface structure investigation in the Siang Valley of the Eastern Himalaya, Northeast India

(D.K. Yadav, Devajit Hazarika, Naresh Kumar and A.K. Singh)

The antiformal structure of the Eastern Himalayan Syntaxis (EHS) exposed in the Arunachal Himalayan region shows bending of the lithotectonic units in their regional strike from NE-SW in the western limb to NW-SE in the eastern limb (Fig. 33). Four major lithotectonic units viz. Sub Himalaya, Lesser Himalaya, Higher Himalaya, and Trans-Himalaya are well recognized. The Sub Himalayan zone is present only in the western limb of the EHS and is characterized by Early Miocene to Lower Pleistocene sedimentary sequences of the Siwalik Group. Its northern limit is demarcated by the Main Boundary Thrust (MBT) separating it from the Lesser Himalayan zone while in the south it is separated from the Brahmaputra alluvium by the Main Frontal Thrust. The Lesser Himalayan zone is tectonically separated from the Higher Himalayan zone by the Main Central Thrust (MCT) in the north. It comprises of three main lithotectonic units, namely the

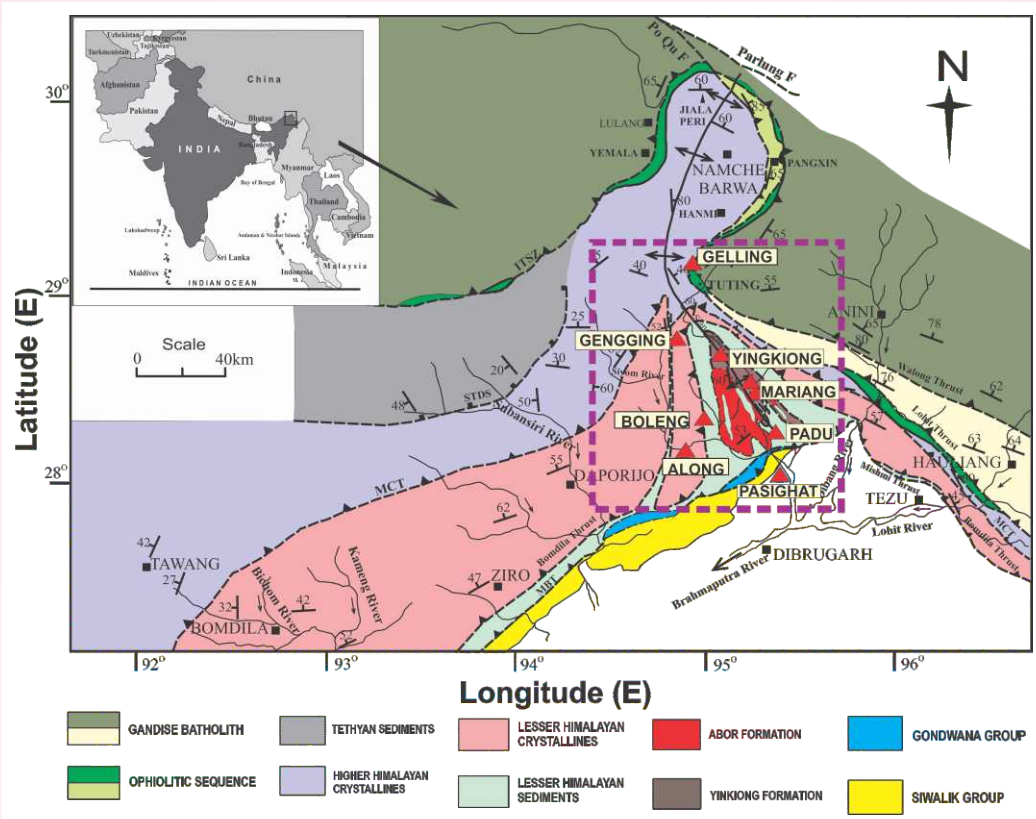

Fig. 33: Geological map of eastern Himalayan syntaxis (Choudhari et. al 2009) showing the locations of seismic stations (red triangles) of Siang Valley, Arunachal Pradesh.

Gondwana Group, Lesser Himalayan sedimentary sequences, and Lesser Himalayan crystallines. In Siang valley, Gondwana Group occurs discontinuously along with the MBT and as a window in the core region of the Siang antiform. The Lesser Himalayan crystallines occur either as synformal klippen over the Lesser Himalayan sedimentary sequences or as a roughly continuous belt below the Higher Himalayan crystallines (HHC).

At the core of the Siang window of the EHS, meta-sedimentary rocks of Miri-Buxa Group are interbedded and co-folded with the mafic-felsic volcanics of Abor Formation and sedimentary rocks of Yinkiong Formation. The rock units within the Siang window are dissected by several subsidiary normal faults oblique to both, the MBT and the North Pasighat Thrust (NPT). To the south, the rock units of the Siang window are truncated against Neogene Siwalik sediments across the NPT.

The Eastern Himalaya syntaxis (EHS) is a seismically and tectonically very active region of the world, it falls in the zone-V, in the seismic zoning map of India. This region has experienced two great earthquakes (M=8.7), the 12th June 1897 Shillong earthquake, and the 15th August 1950 Assam earthquake of the same magnitude. To carry out a detailed study in the epicentral zone of the Assam earthquake, we installed 08 Broadband seismic (BBS) stations in the Siang Valley (Fig. 33). During this period the installation/construction of pit and hut for two remaining seismic stations (e.g Along and Gelling) are undertaken. We had already planned the seismic network with probable site locations and tried to select a site at the remote and approachable place with good signal to noise ratio (SNR). Figure 34 shows the Data Acquisition System at Pasighat Seismic station in Siang valley of Arunachal Pradesh, and a local earthquake event recorded at Pasighat seismic station. During this period two seismic stations are installed:

1. Yingkiong, Upper Siang district, Arunachal Pradesh.
2. Gelling, Upper Siang district, Arunachal Pradesh.

The first phase of digital seismic data from these newly installed seismic BBS stations of WIHG is collected in May 2019. Local and regional earthquake data of over 200 events are extracted and processed to observe the seismicity pattern. In the month of April-2019, this region was jolted by a moderate size earthquake with magnitude 5.9, which was located north of MCT, between the townships of Mechuka

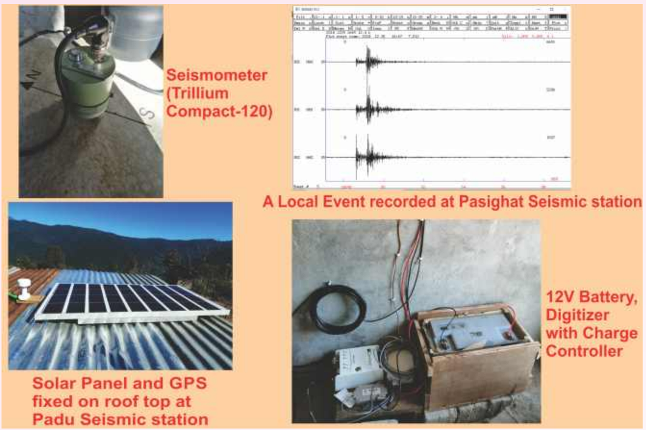

Fig. 34: Figure shows the Data Acquisition System at Pasighat Seismic station in Siang Valley of Arunachal Pradesh, and a local earthquake event recorded at Pasighat seismic station.

(MCK) and Kaying in West Siang district, Arunachal Pradesh, with shallow focal depth (15km). Its fault plane solution has thrust mechanism with nodal planes dipping in the NE-SW direction. This nodal plane is having a very low angle thrust dipping towards northwest perpendicular to major tectonics. We compiled six stations waveform data of this present network and also included waveform data of LASA station (ISC) to determine the focal mechanism solution using P-wave first motion as well as waveform inversion (ISOLA) for this mainshock and its aftershocks. Based on this seismic network (WIHG) we could locate micro-earthquake activity up to magnitude 1.0 in the Siang Window area. The distribution of hypocentres of seismic events is up to 45 km, and the trend of hypocentre indicates increase of depth from west to east (Fig. 35)

Preliminary investigation of crustal structure study in Siang window

Preliminary investigation of crustal structure have been carried out beneath 6 broadband seismological station located in the Siang window, Eastern Himalayan Syntaxis (Fig. 36). We applied iterative deconvolution method of Liggoria and Ammon (1999) for computation of receiver functions. Total 100 teleseismic earthquakes recorded during 4 months period have been selected with M $\geq$ 5.5 and epicentral distance 30-95°. The distribution of selected earthquakes are shown in the inset of figure 36. The individual RFs at each stations are plotted with respect to back-azimuths (BAZ) to investigate azimuthal variation of crustal structure if exists. Example of RFs at each stations are shown in figure 37. Comparison of crustal thickness with Lohit valley region (Hazarika et al., 2012) suggests a SE dipping structure of Moho in NE fringe of the Indian plate in the EHS (Fig. 37b). We adopted H-k stacking

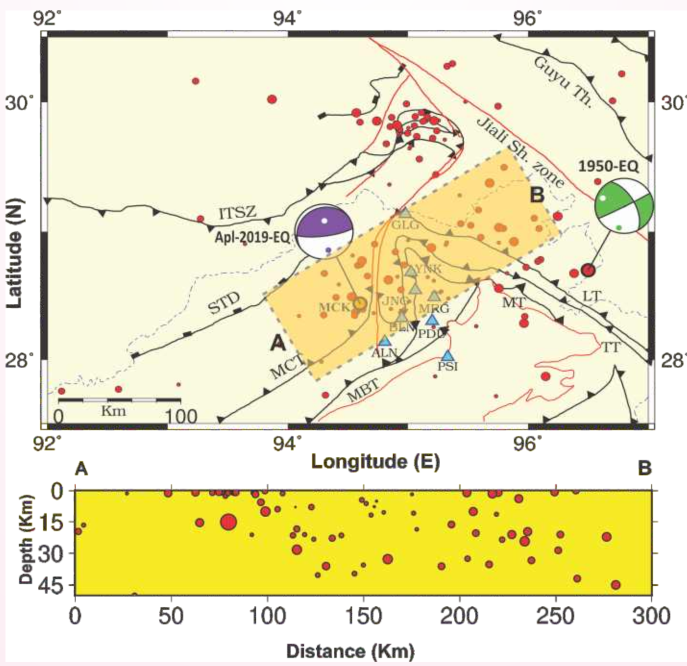

Fig. 35: Microseismicity map of Siang Valley, Arunachal Pradesh, NE-India based on the data of December 2018-May 2019, along with the major tectonic features as follow: STD (South Tibetan Detachment), MCT (Main Central Thrust), MBT (Main Boundary Thrust) and Indus Tsangpo Suture zone (ITSZ). The triangles (Cyan) are the BBS seismic stations installed in the Siang Valley with their Cross-section through A & B below it. The beach balls are of the 1950 Assam earthquake (green) and March 23rd April 2019 earthquake (purple).

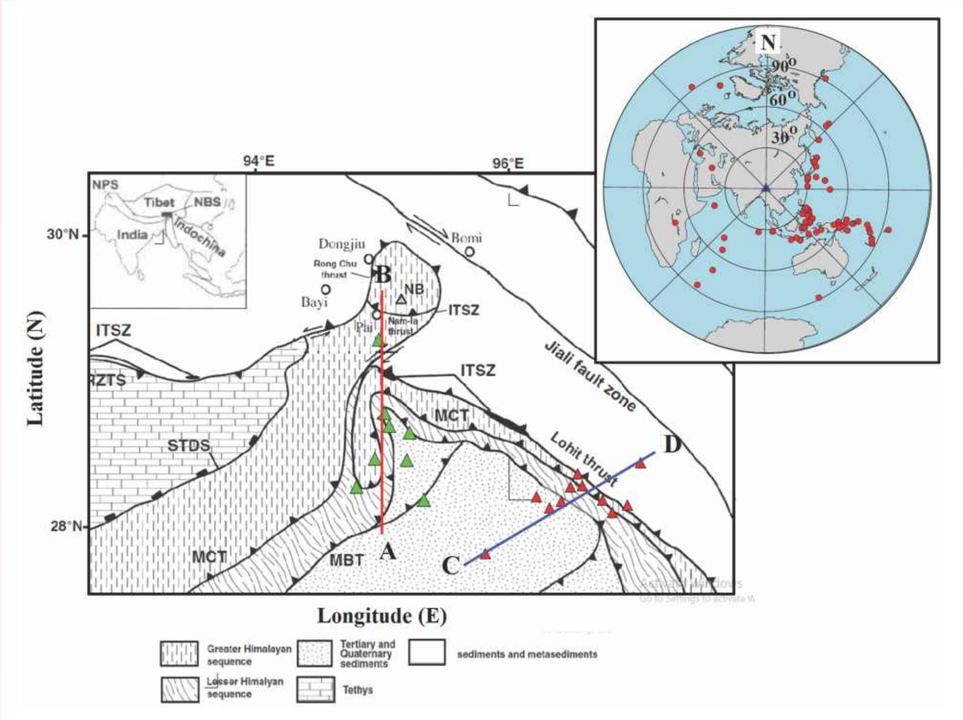

Fig. 36: Simplified tectonic map of the Eastern Himalayan Syntaxis (modified after Ding et al., 2001). The seismological stations of Siang window and Lohit valley networks are shown by green and red triangles. The inset shows distributions of teleseismic earthquakes recorded by BBS stations of Siang window. These earthquakes are used for receiver function analysis. The major tectonic features are: (1) Main Boundary Thrust (MBT), (2) Main Central Thrust (MCT), (3) South Tibetan Detachment (STDS) and (4) IndusTsangpo Suture Zone (ITSZ).

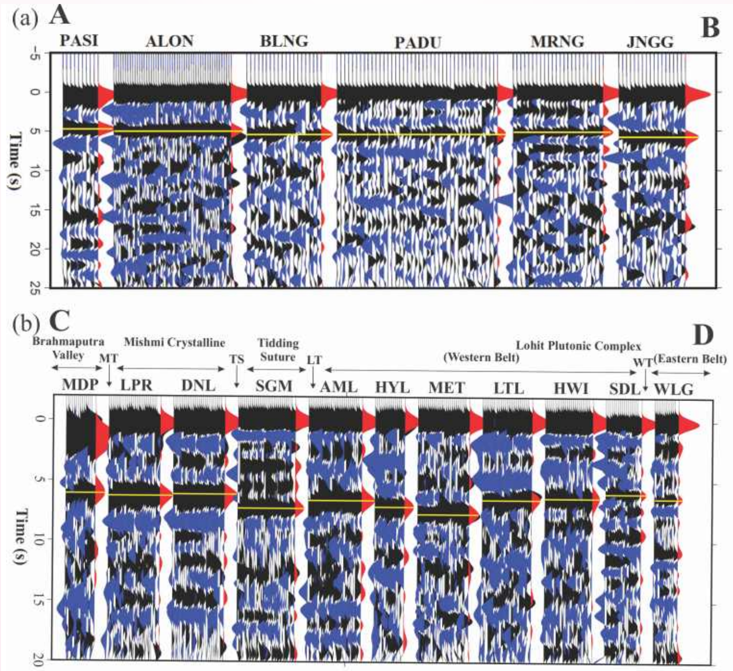

Fig. 37: Receiver functions along (a) AB profile passing across the Siang window and (b) individual receiver function along CD profile (after Hazarika et al., 2012). The red waveforms at each station shows stack receiver functions. The crustal structure can be compared between the two profiles based on delay time differences of P-to-S converted phases originated at Moho.

method of Zho and Kanamori (2000) for analysing the RFs at Pasighat (PASI), Along (ALON) and Mariyang (MRNG) stations to obtain the estimates of average crustal thickness and Vp/Vs or Poisson's ratio of the crust. Example of H-k stacking analysis at ALON station is shown in figure 38. The H-k staking analysis

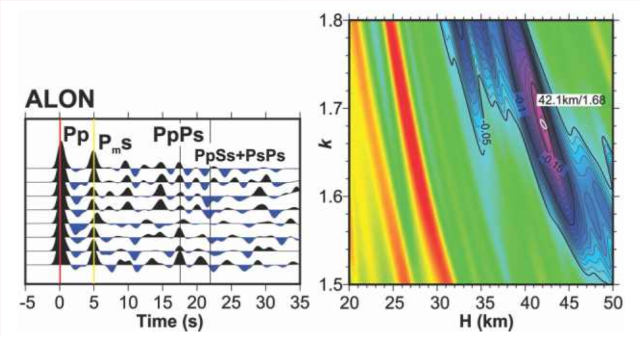

Fig. 38. Results of H-k stacking of ALON station with selected RFs on the left panel. The arrival of Pp phase is marked by red line while the Moho converted Pms phase and its crustal multiples (PpPs and PpSs+PsPs) are marked by yellow, black and blue lines, respectively. The Vp/Vs or k versus crustal thickness, H, for DNL radial RFs is shown in the right panel. The crustal thickness beneath DNL is 42 km, and the average crustal Vp/Vs ratio is ~1.70 given by the center of error ellipse in the contour plot. The corresponding Poisson's ratio (σ) is 0.24.

reveals a low Vp/Vs ratio at the PASI and ALON stations and comparatively higher value (1.77) at MRNG station. The crustal thickness among these stations vary within ~40-47 km. The processing for rest of the stations is in progress.

TAT 3.3

Timing, size, and lateral extent of earthquake ruptures along the Himalayan Frontal Thrust, Dauki-Dapsi and Naga Thrust, Schuppen Thrust Belt

(R. Jayangondaperumal, Pradeep Srivastava and Swapnamita Vaideswaran)

In the northwest Jammu sub Himalaya, a ~200 km long Surin Mastgarh anticline (SMA) marks the active deformation front without emergent Himalayan Frontal Thrust (HFT) on its southern forelimb unlike the central and eastern Himalayan front (Fig. 39). Published literatures proposed divergent kinematic models and shortening rates associated with the SMA during the Quaternary Period, but we estimated congruent geological shortening rate and have provided viable model for the evolution of SMA. Toward this, we use a long profile of deformed strath terraces preserved along Chenab and Munavar Tawi rivers constructed through Real Time Kinematic GPS (RTK-GPS), abandonment ages of terraces, and have estimated the geologic shortening rate across the SMA as ~ 4-6 mm/year, with

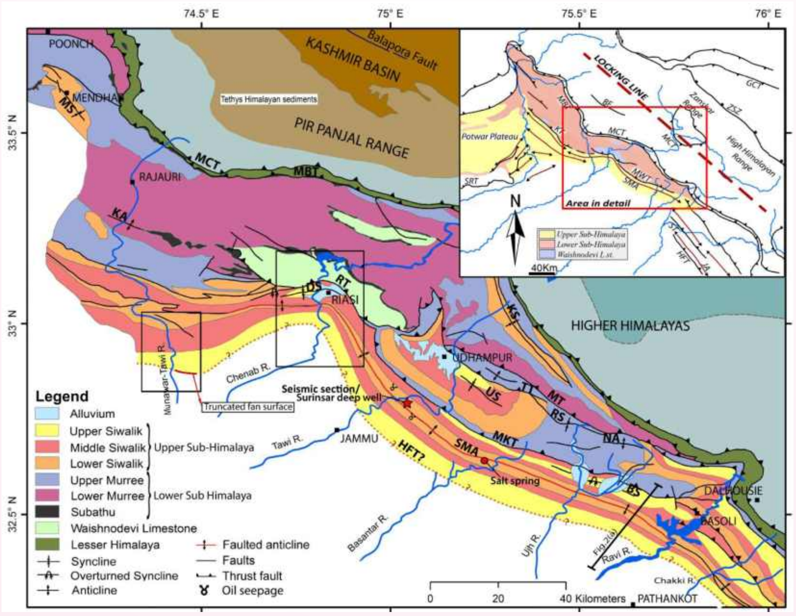

Fig. 39: Geologic map of the NW Himalaya (adapted from Raiverman et al., 1994; Srinivas and Khar, 1994; Gavillot et al., 2016). Black boxes indicate location of study areas within the Jammu & Kashmir region. ONGC deep well location (red star mark) and oil seepages are also shown as red dots and stars. The inset shows the regional map of the area with the structural elements adapted from Gavillot et al., 2016. Regional Locking line (red dashed line) adapted from Schiffman et al., 2013. (HFT: Himalayan Frontal Thrust, SMA: Surin Mastgarh Anticline, MKT: Mandili Kishanpur thrust, MT: Murree thrust, RT: Reasi thrust, MBT: Main Boundary Thrust, MCT: Main Central Thrust, SRT: Salt Range Thrust, KT: Kotli Thrust, BS: Baniyari syncline, US: Udhampur syncline, JA: Janauri anticline

vertical uplift rate of ~2 mm/yr since 29 ka. The inferred rate is similar to the long-term geological rate estimated through excess area method integrated with seismic section and magento-stratigraphy age, and it also corroborates with the reported geodetic rate of ~11 mm/yr across the Jammu & Kashmir Himalaya.

Given the field evidence together with the geometry of arcuate terrace profiles, structural data, trench investigation, and drainage analysis presented in this work, we propose that the SMA grew as a long-lived detachment fold, but with late stage modification as an outward propagation of fold (OPF), especially toward the southeast with crestal graben. Our results imply that a generalized seismotectonic model in the central Himalaya can't be considered in this NW segment of Jammu sub-Himalaya, and an alternative model is proposed.

TAT 3.4

Neotectonics between North Almora Thrust (NAT) and Himalayan Frontal Thrust (HFT) of Kumaun Himalaya: Implication to morphotectonic evolution

(Khayingshing Luirei and S.S. Bhakuni)

Evolution and morphology of landform were studied particularly in the MBT zone of Ukhaldhunga area in Kosi River valley with special reference to tectonically induced landforms; landforms of fluvial genesis and landforms formed by mass movement/landslide. Lineaments analysis have also been carried out, which may be a result of tectonic fabric, lithological control such as bedding or erosional features. The evolved morphology of landforms is discussed in detail based on the field evidences and analysis of Google Earth Images. Active fault trace of the MBT is observed in the Google Earth Image between Dhauli gadhera and Bhakrakot gad (Fig. 40). The NW-SE trending active fault trace measures about 8 km in length. In this segment the hanging wall block has moved downward with respect to the footwall of the MBT as such the fault trace are visible. The fault activity postdates the deposition of landslide debris fan at Bhakrakot; as Bhakrakot is nestled on old landslide debris. Landforms related to normal faulting along the MBT, form a characteristic nature of valley developed in the Baurar gadhera, a tributary of the Kosi River. In the hanging wall block of the Baurar gadhera the valley is wide about 450 m while in the immediate footwall block the valley is a few metres wide only. The Kosi River also shows similar feature in the MBT zone, in the basal part of the hanging wall block of the MBT, the Kosi River valley is about 800 m wide while in the immediate footwall block it is about 80 m wide. The bedrocks in the

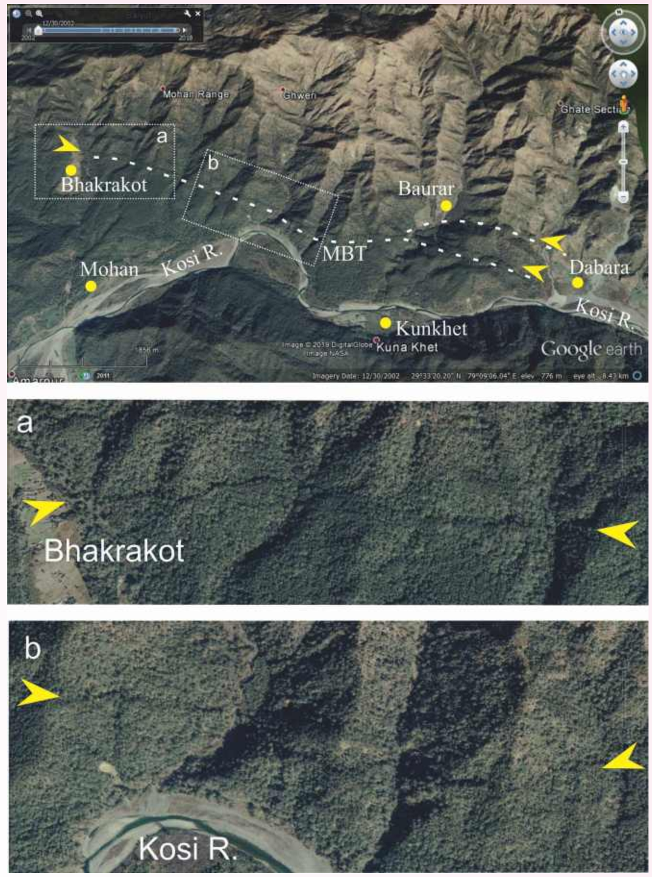

Fig. 40: Google Earth images showing active fault trace along the MBT between Dabara and Bhakrakot. (a) and (b) are the enlarge portions of the active fault trace.

MBT zone are very steep to vertical and are highly sheared. The fan deposit exposed at Gaunchhil gadhera shows gently (1-2°) dipping stratification towards north, while the lower younger terrace deposit is tilted by about 5-7° towards north. These tilted fan and terrace are situated in the hanging wall block of the MBT. At the southern end of Ukhaldhunga uplift, some paleochannels are observed in the form of valley fill deposits.

Fluvial geomorphology has been carried out for a stretch of about 15 km in length for analysing the valley floor geomorphology for the present study. Seti Talla is the upstream extremity of the Kosi River where four levels of unpaired filled terraces are observed, which are T_4 at 697 m asl; T_3 682 m asl; T_2 m asl and T_1 658 m asl. Exposed section of T_3 is characterized by presence of upward fining sequence, where the base is made up of rounded to angular clast of the Lesser Himalayan rocks, followed upward by coarse sand and silt. The terraces are small in extent as compared with other sites. Seven levels of unpaired terraces are observed at

Ukhaldhunga, some are well developed while some occur in patches as a result of erosional activities (Fig. 41). The highest level of terrace (T_7) is developed at 640 m asl and the most widely developed in terms of area. A paired terrace is observed at three sites situated along both sides of the Kosi River at Ukhaldhunga. Type of this terrace is compound terrace because it is formed by fluvial deposit as well as landslide deposit. T_6 is developed at 620 m asl, T_5 at 618 m asl, T_4 at 604 m asl, T_3 at 600 m asl, T_2 at 590 T_1 at 588 and T0 at 586 m. Older terraces T_7-T_3 are composed of very angular to well-rounded pebbles and boulders. In the northern part of Ukhaldhunga village, T_2 is a strath terrace where the bed rock of phyllite is overlain by 2 to 3 m thick stratified fluvial deposit. T_1 is composed mainly of clasts of quartzite, phyllite and shale. It is exposed mainly along the southern extremity of the village along a small stream. The youngest terrace is made up mainly of coarse to medium- grained sand. At Dabara village, one level of terrace is observed, which is made up of both reworked fan and river deposit. Its best section is observed along gully erosion where the sediments are laminated and composed of angular to sub rounded clasts in a matrix of coarse sand. In the immediate downstream of the MBT at Kunkhet, only one level of terrace is developed at 540 m asl while the present active river bed is at 536 m asl. Strath terraces are observed at different areas and at different heights. In some cases these terraces represent the paleochannels. At Basela, strath terrace is observed at 641 m asl, the river borne sediments of more than 25 m are deposited on highly fractured quartzite bedrocks of the Nagthat Formation.

Paleochannel of the Kosi River is observed in this terrace. In the northeastern part of Ukhaldhunga, a single paleochannel of the Kosi River is observed, which in the field is represented by a hanging valley. The width of the paleochannel is about 180 m and there is no alluvium cover on the bedrock. Towards the southwestern end of Ukhaldhunga village, different stages of migration of the Kosi River are evident from presence of different levels of the paleochannels at T_7. A 35 m wide Paleochannel has incised the T_2 and a strath terrace. In the field, this 3 m thick strath terrace is made up of phylitic rocks, and is overlain by thin veneer of fluvial sediments. Towards the western site of Ukhaldhunga in the immediate footwall block of the MBT, a 2-3 m high strath terrace made up of highly indurated sandstones of the Siwalik is observed. Here the NW-SE striking bedrock of the Siwalik is almost vertical.

In the study area a total of 4563 lineaments were delineated. The population of lineaments deduced from the rose diagram is seen to occupy four dominant sets of trends, viz. NNW/SSE, NW/SE, NNE/SSW and NE/SW directions that correspond to the tectonic activities associated with the NW-SE trending MBT and its transverse fault settings. In addition to this, 350 of the other major trends of lineaments can be interpreted as NNE-SSW trending normal faults, NW-SE trending

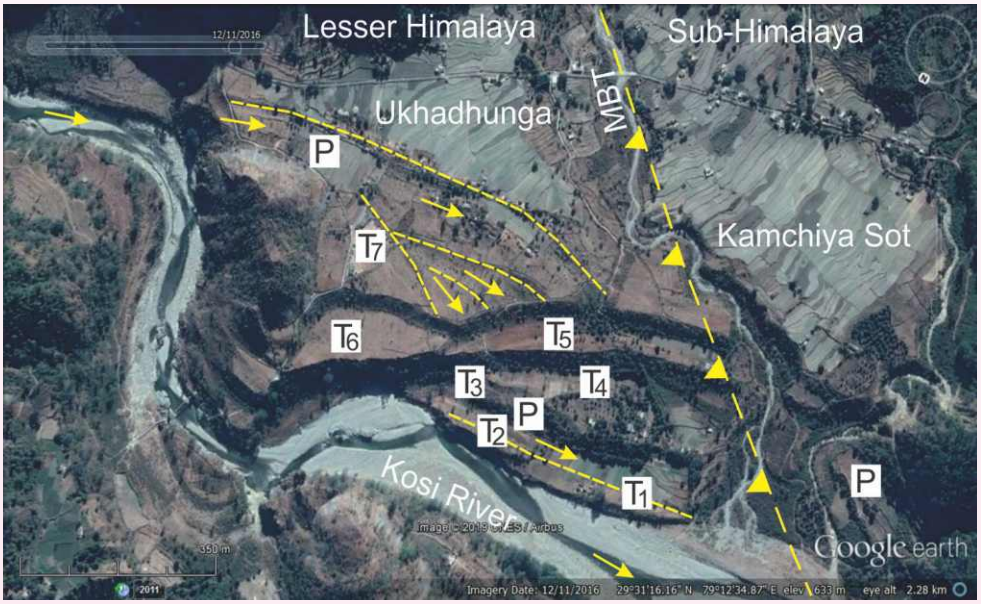

Fig. 41: Google Earth image showing various levels of terraces, strath terraces and paleochannels in Ukhaldhunga area of Kosi River valley. (In the figure P stands for paleochannels).

wrench faults and strike slip faults (synthetic shears) and NE/SW as strike-slip faults (antithetic shear). This inference drawn is based on comparison with the geometric and kinematic data acquired from clay-model studies by Wilcox et al. (1973) and Sylvester et al. (1976). From the lineament map, most of the lineaments are transverse to the regional trend of major structure of the Himalayan fold-thrust belt. Of the total lineament delineated 16% (733) are transverse, 61.61% (2812) are oblique, while 22.3 (1018) are parallel to the general trend of the Himalaya orogen. The highest concentration of lineaments is observed in the northern purchase part of the map; while obviously a relatively less density is observed in the Gangetic plain as well as in thick alluvium which overlain the bedrocks and are observed as Patkot fan and Chopra fan areas. In the Ross diagram 57.17% falls in NE-SW trend while the remaining in NW-SE trend. Numerous old and active landslides are observed in the MBT zone. Very thick landslides debris is observed in the hanging wall block of the MBT and the thickest debris are along the Kamchiya Sot. The thickness measures >60 m, and along the road cut section two phases of landslides are clearly discernable on the basis of the different morphology of stratification of clasts of the landslide debris, otherwise different phases of landslides are difficult to differentiate. Maximum number of landslides are observed in the hanging wall block of the MBT; while in the footwall block fewer landslides are seen. In the present observation, the hanging wall bedrocks are highly fractured with multiple joint sets in quartzite and phyllite; while the footwall block is made up of highly indurated sandstone of the Lower Siwaliks that are less deformed. Most of the landslides are the result of joints that are formed during the successive movement along the faults. The intersection joints and joint sets form wedges which further weakened the slope making materials.

TAT 3.5

Late Quaternary landform evolution and active tectonics in the selected segments of northwestern Sub Himalaya between Kali-Ganga-Beas rivers

(G. Philip, N. Suresh, Gautam Rawat, S. Rajesh and P.K.R. Gautam)

Quaternary landforms evolution in the Kota-Pawalgarh duns

The Kota-Pawalgarh duns in the Kumaun Sub-Himalaya is studied to understand the tectonic process and the prevailing climate in the evolution of the Late Quaternary alluvial fan and terrace deposits. Alluvial fans, river terraces and up warped areas were identified and dated in the Kota-Pawalgarh duns, along Himalayan frontal Thrust and along the Kosi River. In the Kota Dun, four alluvial fans, namely Kotabagh, Dechauri, Patkot and Chopra fans were deposited in front of the uplifted Siwalik Mountain, comprising Lower Siwalik rocks, along the Dhikala Thrust. Of these, the Kotabagh and Dechauri fans were studied in details. The Kotabagh Fan is oriented in the NE to SW direction, with the apex at the Lower Siwalik Mountain in the north and the toe terminated at the up warped area in the south. Whereas, the Dechauri Fan is oriented in the NE to SW direction in the proximal to mid fan region and towards SE at the distal part, with the apex of the Lower Siwalik Mountain in the north and the toe terminated at the Upper Siwalik Mountain along the Himalayan frontal Thrust (HFT). The profiles constructed along the fans show that the fan surface is gradually sloping. Towards south, an up warped area was identified and the beds are tilted towards the NE (< 10^{o} dip).

Timing of the aggradation and incision of the alluvial fans in the Kota Dun has been established using quartz OSL dating. The ages obtained from the Kotabagh Fan gives ~26 ka towards the bottom of the section, followed by 17 ka and 11 ka at the surface. The ages obtained from the up warped area to the south of the Kotabagh Fan gives ages of ~59 ka at the basal part and 30 ka at the surface. This reveals that the up warped area received sediments between 59 and 30 ka and after this the area has uplifted due to tectonic activity. From the mid fan area of Dechauri Fan, an age of ~11 ka is obtained close to the fan surface and ~16 ka at few meters below the surface. This reveals that the fan aggradation phase was continued at least since 16 ka and terminated after 11 ka. However, from the distal part of the fan near HFT, an older age of ~30 ka is obtained close to the fan surface and this reveals that the fan depositional phase in this locality has abandoned after 30 ka. This reveals that the deposition phase stopped in the distal region of the fans due to uplift and a piggyback region is formed to the north of the uplifted area, where the fan sedimentation continued until 11 ka. The available oldest OSL age of 59 ka from the basal part of the up warped area and a young age of 11 ka from near surface reveals that the fan aggradation was probably initiated well before 59 ka and continued until 11 ka.

The deposition of alluvial fans in front of the Lower Siwalik Mountain reveals that the tectonic activity along Dhikala Thrust has created source area relief and hence sediment erosion as well as accommodation space for sediment storage. The abandonment of Kotabagh and Dechauri fans deposition phase is occurring with fan surface incision by Dabka and Baur rivers respectively. The fan entrenchment resulted vertical scarps parallel to the rivers and the subsequent lower level of terrace deposits occur below the fan surface. In an active tectonic domain, the fan evolution is influenced by tectonic deformation or climate change and/or both. In the tectonically active intermontane basins of Sub-Himalaya region, the evolution history of late Quaternary alluvial fans is either correlated to climatic oscillations or tectonics. The termination of fan deposition in the Kota-Pawalgarh duns coincide with reported increased ISM phase. The inter-glacial warm and humid climate produces more vegetation in the source area and less sediment production for erosion thus exerts variation in sediment: water ratio. Time equivalent incision phase related to climate change has been documented from Soan Dun, Pinjaur Dun and Dehra Dun and suggests that the incision phase is regional. This reveals that the tectonics initiated source area relief and erosion while the climate changes controlled the fan aggregation, duration of deposition and river incision.

In the Kota Dun, two to three levels of terraces were formed by Dabka River to the west of the Kotabagh Fan and four levels of terraces were formed by the Baur River to the east of the Dechauri Fan since 11 ka. Few of these terraces were seen on both the banks of the rivers and are paired. In Dabka River, an age of 3 ka is obtained for a terrace deposit (T2) occurs around 6 m from the river level. In Baur River, the top most terrace (T4) below the fan surface gives 10 ka age. This reveals that the river has undergone major incision phase since 11 ka with minor depositional phases in between in the form of depositions or erosional terraces. This incision phase continued in Holocene with minor depositional/non-depositional phases in between and has 5 terraces including the fan surface.

At the proximal part of the fans, the Lower Siwalik Subgroup rock is riding over the fan sequences along the NW-SE trending Dhikala Thrust. The Kotabagh and Dechauri fan surfaces and the next lower level of the terrace (T4) along Baur River were displaced across the Dhikala Thrust, which suggest that tectonic movement after 11 ka. The documented 40-50 m vertical offset between the fan surfaces across the Dhikala Thrust suggest tectonic movements has displaced the fan surface a cumulative displacement of 40 to 50 m. The subsequent lower terrace (T4) has also displaced across the thrust, but only 30 m offset was measured. The variable off-set measured between the fan surface and terrace suggests multiple tectonic activity along the Dhikala Thrust. The initial and or reactivated tectonic activity along Dhikala Thrust has occurred before the initiation of the alluvial fans. However, after the termination of the fans around 11 ka, the Dhikala Thrust has reactivated and displaced the fan surfaces. This is followed by T4 terrace deposition around 10 ka and its displacement across the thrust. This suggests the Dhikala Thrust has moved multiple times and is an active thrust in this locality.

Tectonic activity along the HFT is also evident in this locality. In the region between the Baur and Kosi rivers, the HFT is segmented and lateral shifts were observed along transverse faults. Escarpments, entrenched streams and abruptly truncated river terraces across the HFT were observed, which suggest the HFT is active. In places, abandoned channel and wind gap were identified and this suggests tectonic movement along HFT.

Electrical resistivity studies across HFT at Kala-Amb

One of the aspects of active tectonic studies in a seismogenic region is to identify and characterize major active faults. In doing so, primary emphasis is on geometrical, kinematical and chronological parameters of the morpho-structural features, if any (Caputo et al., 2003) on the surface or in an excavated trench. Near surface geophysical imaging can add another dimension to our understanding towards the analysis of seismic hazard assessment of the region by providing information about the subsurface extension of such surface features to a greater depth as compared to a possible deep trench and without excavation. The ERT methods was employed at a site in Kala-Amb where trench excavation survey indicate three active fault zones in the Quaternary (Fig. 42). The 2D inverted resistivity section represented subsurface geology in terms of variation in resistivity (Fig. 43). Three distinct zones of different litho units based on resistivity estimation could be clearly identified. The resistivity methods helped to distinguish each sedimentary unit as a different resistivity zone and vertical displacements in the Quaternary. The Fault plane is identified as a displacement in resistive feature could be correlated with fault delineated in the trench log. The liquefaction feature as identified in the trench is also correlated with sub vertical emergent low resistive feature from the subsurface. The results of ERT studies clearly indicate that resistivity studies are highly useful and can be an integral part of studies on active tectonics. This will surely serve as guiding reference towards planning and finalizing a site for paleoseismological studies where trench excavation is as an integral component of the study for final trenching.

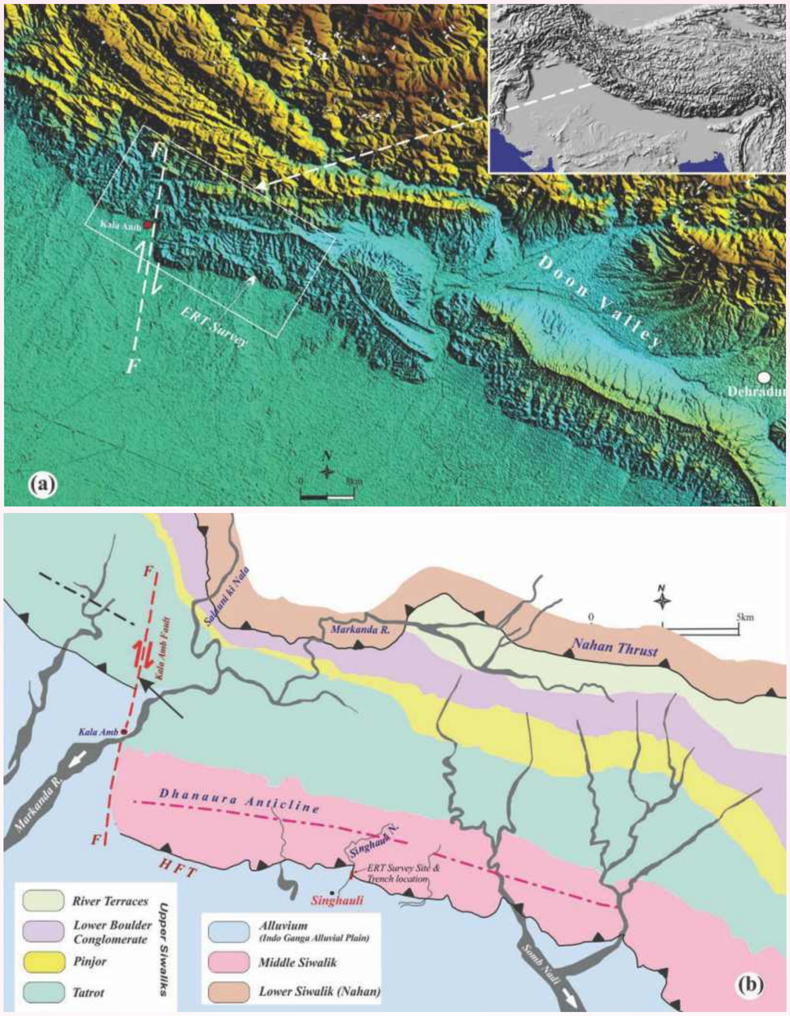

Fig. 42: (a) Satellite image (SRTM) showing the location of the study area (b) Geological map showing major lithological and structural features of the frontal Himalaya.

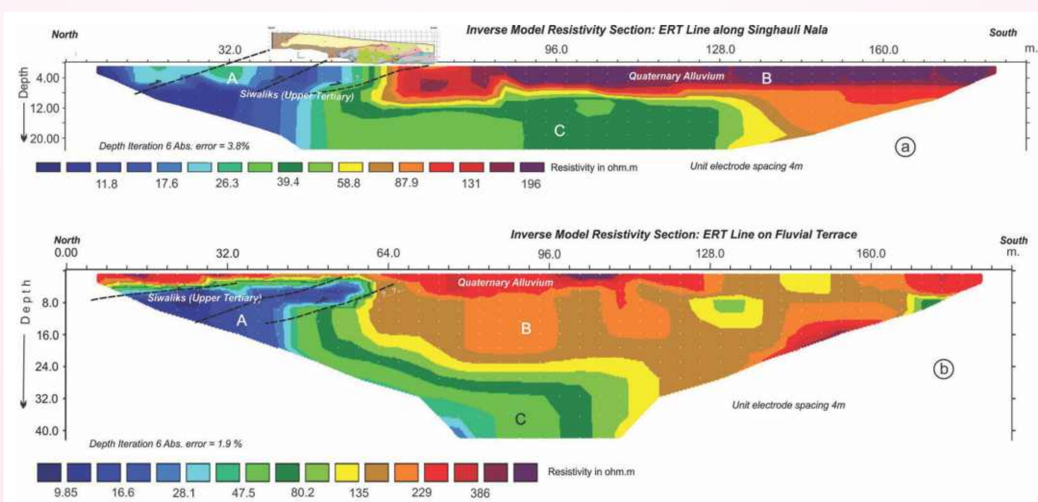

Fig. 43: Resistivity sections obtained after the inversion of ERT profiles carried out along (a) Singhauli Nala (River bed) site and (b) Fluvial Terrace situated NW of Singhauli Nala and sub-parallel to profile A. Trench log is aligned with a resistivity section at (a). The major three units as per the contrasting resistivity variations are A, B & C.

Geodetic Studies

Being the southernmost plate boundary thrust, the kinematic behaviour of Himalayan Frontal Thrust (HFT) evince greater interest not only for the paleo-seismologist but also for the Geodesists. The main concern here is how the different kinematic modes of strain can be estimated by considering the strain accumulation and release processes at different time scales and hence to constrain the overall strain budget. Although being a mega fault structure, the frontal fault HFT is umbilical to many small active fault systems that are present mainly in Sub-Himalaya with a few in the Lesser Himalayan region. The role of these active fault systems in conjunction with the frontal HFT in re-distributing the strain energy; whether they aid strain diffusion or accumulation was one of the objectives of this study. This has greater importance because all these small shallow active fault systems are present right over the most coupled and highly locked portion in the up-dip of the sub-surface mega thrust MHT. This has been attempted by understanding the correlation between long term Geological and short term Geodetic deformation rates of these active faults in terms of their uplift or subsidence rates, fault parallel and perpendicular velocities, shortening rates etc.

The underlying mechanism behind the long and short term strain energy release or accumulation mainly in the frontal part is different and this has been studied by selecting two active fault systems, namely, the Pawalgarh and the Dhikala thrusts in the Ramanagar-Haldwani Area, where a close network of GNSS stations were installed for the periodic survey. The network comprises six stations covering both these faults and semi-permanent GNSS antenna fixing points were constructed for the repeated observations at locations as shown in figure 44. Apart from the Ramnagar network, we have simultaneously developed a parallel network in Haridwar, close to the Ganga Tear by adding two more repeated GNSS observation points at the Mansa and the Chandi Hills, where geological uplift and subsidence rates were earlier reported. We have completed three sets of observations in the Haridwar network while two sets of observations have done in the Ramnagar-Haldwani network and further data collection in both these networks are under progress and will continue.

We processed the campaign data along with the existing permanent station GPS data from the Ramnagar-Haldwani and the Haridwar networks using GAMIT/GLOBK and obtained the ITRF-08 combination frame reference velocities and the same is shown in figures 44 and 45 respectively.

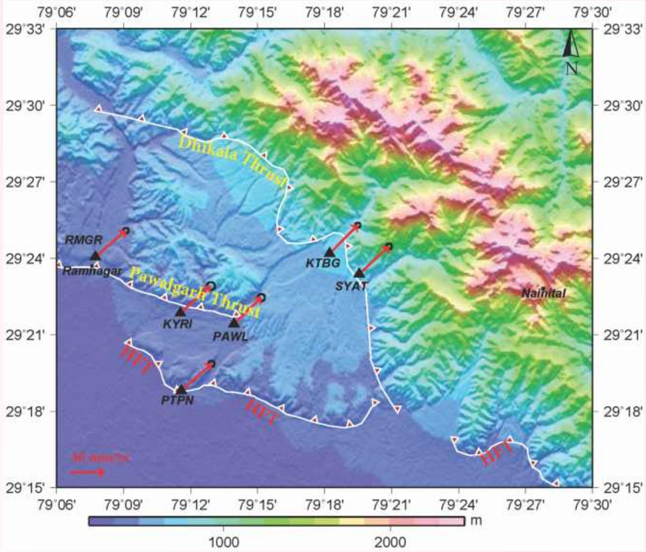

Fig. 44: ITRF-08 combination frame reference velocities of stations from the Dhikala and the Pawalgarh active thrusts in the Ramnagar-Haldwani network.

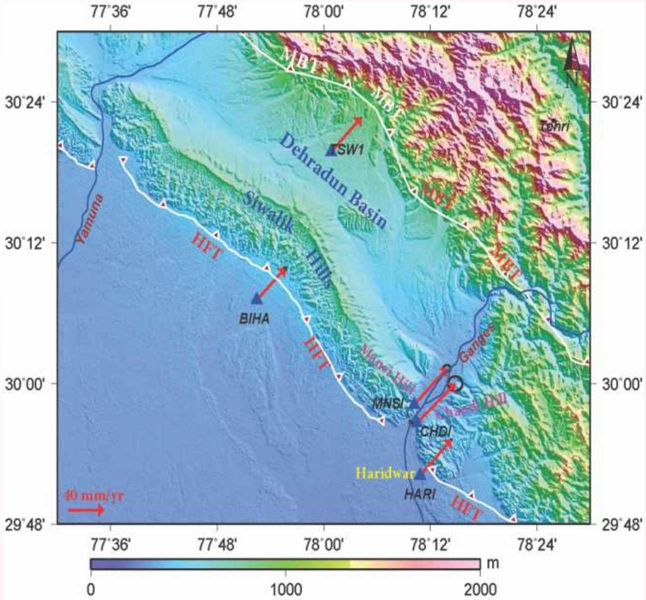

Fig. 45: ITRF-08 combination frame reference velocities of stations from the Haridwar network in the Dehradun re-entrant.

The estimated station velocities show movement towards the NE and are well in agreement with the established movement rates of the regional plate motion. The India fixed velocities are estimated by using Ader pole of rotation. In general, at all stations the India fixed velocities show a SW movement and also directed nearly perpendicular to the strikes of Dhikala and Pawalgarh thrusts along with a minor westerly component along their strikes. We observed that the SE limb of the Pawalgarh Thrust is quite active and shows nearly 6.5 mm/yr and riding over the hanging wall of the HFT. We also compared the geodetic and geological uplift rates of these thrust systems viz. a viz., with the HFT. Initial results show that the geodetic uplift rate of the Dhikala thrust is almost double that of the estimated geological uplift rate obtained through OSL dating. However, nearly comparable uplift rates are obtained for the case of Pawalgarh Thrust and the Frontal HFT. This suggests that the Dhikala thrust that occupies close to the footwall of MBT is relatively active.

We also studied the short term deformation processes in the region, particularly across the Dehradun and the Kangra re-entrants. Figure 45 shows the Haridwar network with the ITRF-08 combination frame velocities along with other stations in the Dehradun re-entrant.

GPS data from the WIHG network has been processed along with the IGS data and obtained the surface velocities with reference to the ITRF-08 and the India reference frame. The estimated velocities are used to model the regional trends of the velocity functions in both Dehradun and the Kangra re-entrants. The velocity functions reflect the inverted impression of the locked portion of the MHT across both the re-entrants. The surface shortening rate in the Dehradun re-entrant is more (17.8 ± 1.4 mm/yr) compared with the Kangra re-entrant (14.3 ± 2.1 mm/yr), while the respective locking widths are inversely related. GNSS data from Biharigarh and Haridwar regions at the frontal part of the Himalaya show subsidence of -9.3 ± 0.7 mm/yr and -9.0 ± 0.4 mm/yr respectively. However, at the northern portion of the HFT and towards the Lesser and Higher Himalaya, the observed average uplift rate is 6.8 ± 0.4 mm/yr. Thus GPS data from the southern part of the frontal HFT is showing subsidence of around 9 mm/yr, while uplift trends are observed in the Sub, Lesser and Higher Himalaya and the concurrent results are also obtained through the InSAR studies using ALOS data.

TAT 3.6
Evaluation of Geomorphic Hazards in the selected transacts of Uttarakhand and Himachal Himalaya
(Vikram Gupta and Ajay Paul)

During the reporting year, the work was carried out towards the preparation of the landslide susceptibility (LS) maps of the Bhagirathi river valley in the Garhwal Himalaya, the Goriganga valley in the Kumaun Himalaya, and also for the hilly township of Mussoorie (Fig. 46). In addition, landslide risk assessment of the Mussoorie township has also been carried out. Besides, in a zone of ~ 10 km on either side of the Main Central Thrust (MCT) in the Uttarakhand Himalaya, we have attempted to relate the spatial distribution of landslides with the spatial distribution of earthquakes of the region. In order to understand the distribution of stress pattern on the slopes, few slopes in the vicinity of the MCT were also modelled using finite element (FE) technique.

There are many methods for landslide susceptibility (LS) mapping, including both qualitative as well as quantitative methods. Since qualitative methods are subjective, and thus the weight assigned to the landslide influencing factors are individual and area specific. In

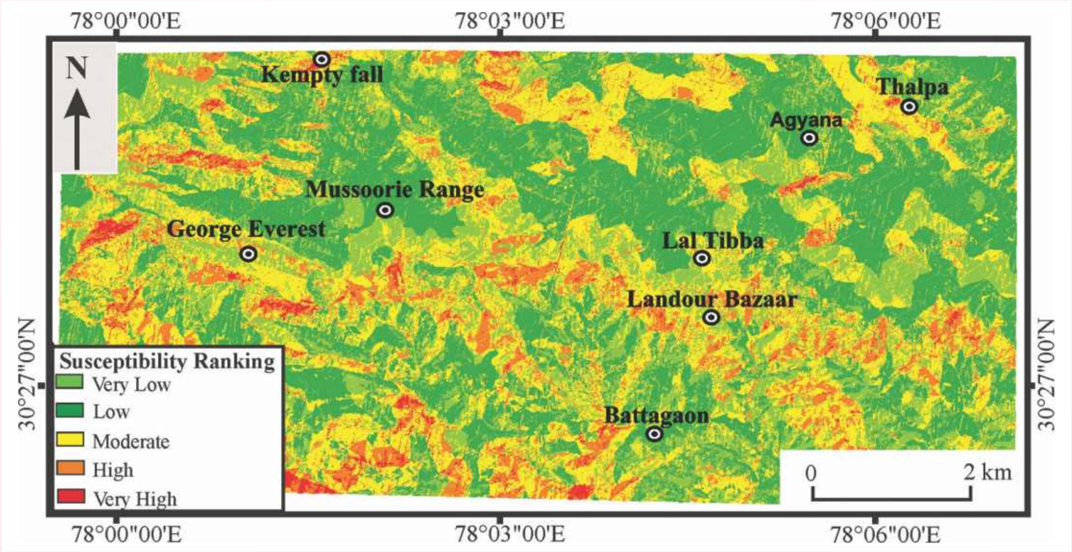

Fig. 46: Landslide susceptible map of the Mussoorie township (Garhwal Himalaya) and its surrounding areas.

order to overcome the subjectivity in the process of weight assignment, quantitative methods were used in the present case studies. For the Bhagirathi valley, advanced machine learning (ML) techniques using information value analysis and support vector analysis have been used, whereas for the Goriganga valley and the Mussoorie township, bivariate statistical Yule Coefficient (YC) method was used. However, various other methods like frequency ratio, information value etc. have also been attempted. The LS maps thus generated using various techniques were validated.

For the preparation of these LS maps, high resolution detailed inventory of landslides was used that was prepared using high resolution satellite images and field visits. Various landslide conditioning factors like lithology, landuse/landcover, geology, geomorphology, lineament, slope, aspects, elevation and curvature of slope, road network and drainage network were utilized to prepare these maps. In order to assess the accuracy of the prepared LS maps, validation of the maps was carried out using success rate curve (SRC) and the prediction rate curve (PRC). Both these curves have been drawn using the cumulative percentage of the study area and the cumulative percentage of landslides, and indicate the accuracy and the predictive value of the LS maps, respectively.

Further the initial observation about the association of spatial distribution of landslides and earthquakes in the MCT zone suggest that there is higher concentration of landslides in the zone of higher seismicity.

TAT - 4: BIODIVERSITY - ENVIRONMENT LINKAGE

TAT 4.4

Characterization of Tertiary fauna and flora from the NE India vis-à-vis NW Himalaya in light of India-Asia collision and global bioevents

(Kapesa Lokho, Kishor Kumar and M. Prakasam)

The study of Paleogene and Neogene fossil investigations the from Indo-Myanmar Range (NE India) for their paleoenvironmental, biostratigraphic, and tectonic implications were continued. A synoptic review of the Eocene-Miocene fossil records of the Indo-Burma Range (IBR), NE India and its paleoenvironmental comparisons with the better documented coeval sediments of the NW Himalaya of India is documented to infer tectonic settings and throw light on the collision of the Indian and the Eurasian plates (Fig. 47). A review of the Eocene-Miocene succession of the IBR (northeast India) and the foreland basin deposits of the NW Himalaya on eastern and western extremes of the Indian Himalaya brings to fore the following inferences:

1. While on the eastern extreme represented by IBR, adjacent collisional regimes allowed marine deposition for a much longer duration till the Miocene but the collisional tectonic environment on the western Himalaya guided marine deposition to end by middle Eocene at equatorial latitudes.
2. Comparable existing biostratigraphic data of the Cenozoic successions of the IBR, northeast India and the northwest Himalaya suggest the plausibility of progressive south-west withdrawal of the Tethys Sea in a stepwise manner due to the episodic associated tectonics in the NW Himalaya but in the IBR, the progressive withdrawal of the Sea is from east to west.

Results of biostratigraphic and geochronological investigations in eastern Nagaland and Manipur, NE India, provide new constraints on the tectonic evolution of the western margin of the Burma microplate. Fine-grained siliceous marine sediments including cherts,

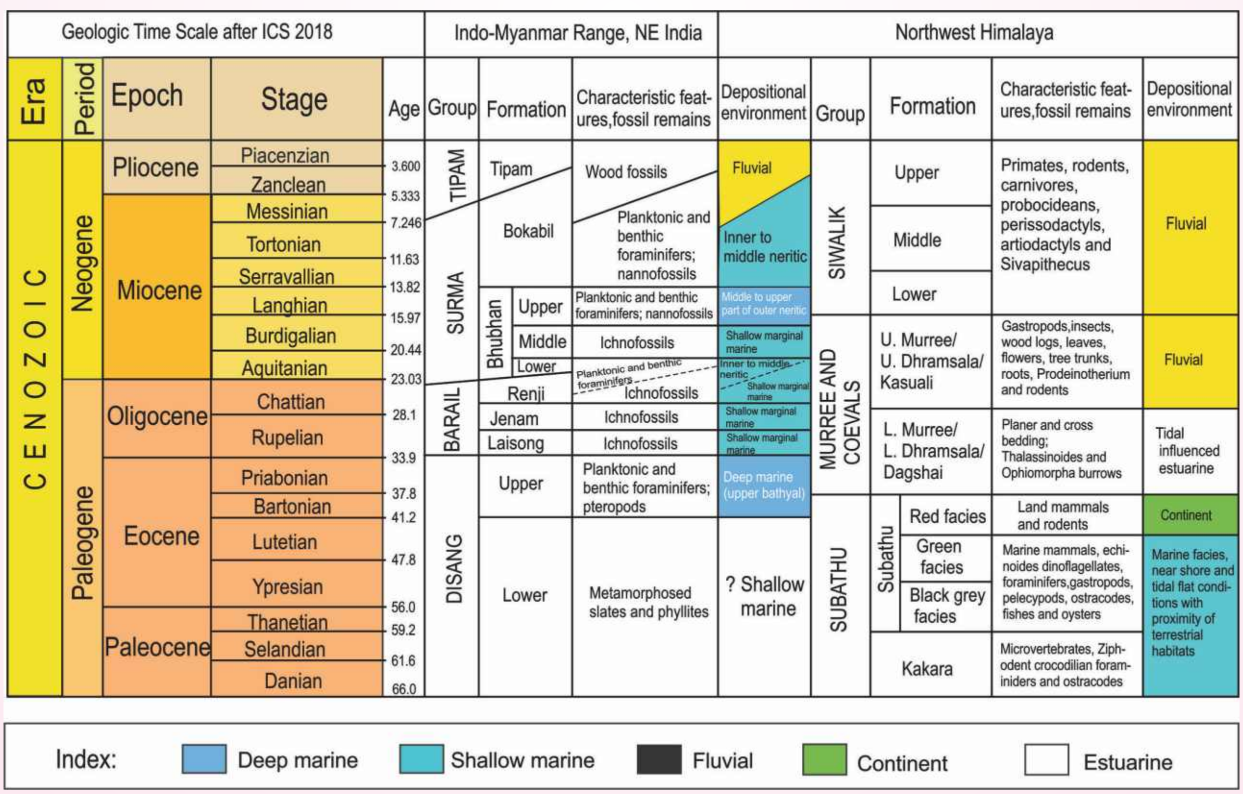

Fig. 47: Stratigraphic units, characteristic features, and depositional environment of the Cenozoic of Indo-Myanmar Range, NE India, and NW Himalaya.

siliceous mudstones, and tuffaceous cherts were collected from numerous localities across eastern Nagaland and NE Manipur. These rocks typically occur as isolated blocks within mud- or serpentinite-matrix mélanges associated with, or directly underlying the Naga Hills Ophiolite. Pioneering studies Acharyya et al., 1986 illustrate numerous fossils but the images are not of sufficient quantity to confirm all taxonomic assignments. Biostratigraphic age ranges in this investigation were determined with reference to other known well-dated radiolarian occurrences (Baumgartner et al., 1995; Gorican, 1994; Gorican et al., 2006; Hollis, 2006; Jackett et al., 2008; O'Dogherty et al., 2006). Paleocene/Eocene radiolarians (Fig. 48) that occur in blocks of thinly bedded siliceous mudstones within mud-matrix melange beneath the NHO provide constraints on the timing of emplacement along the Waziho thrust of the NHO and its overlying

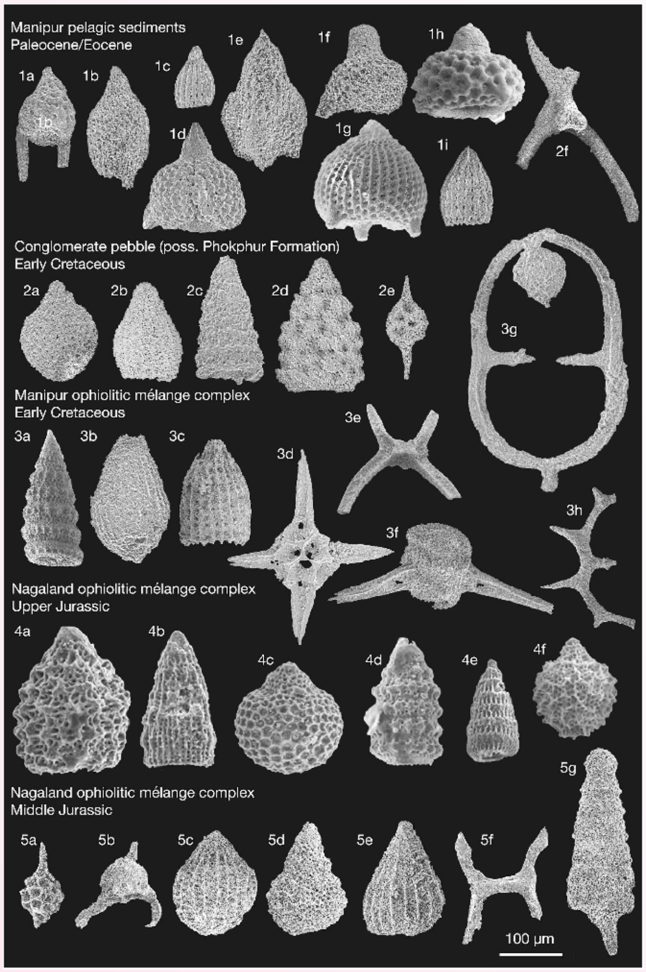

Fig. 48: Composite plate of key biostratigraphically important radiolarian fossils from Jurassic, Cretaceous and Paleocene/Eocene siliceous sediments in Nagaland and Manipur.

cover of Eocene marine sediments in the Phokpur Formation onto India. Fossils reported from this formation are either long-ranging or insufficiently well preserved to allow anything other than a broad Eocene age assignment. However, it was folded together with the NHO melange prior to emplacement over the Disang Formation. The same radiolarian assemblages have been reported from blocks in mud-matrix melanges immediately beneath overthrust ophiolitic nappes in analogous tectonic settings along the length of the IYTSZ (Colchen et al., 1987; Ding, 2003, Li et al., 2018; Liang et al., 212; Liu and Aitchison, 2002; Wang et al., 2017). This may indicate that a Paleocene/Eocene boundary age Ophiolite emplacement event was regionally widespread from Ladakh to Manipur.

TAT 4.5

Biostratigraphy and paleoecology of the Neogene terrestrial Siwalik Group of NW India: a combined study of vertebrate fossils and stable isotopes

(R.K. Sehgal and Aditya Kharya)

A new *Sivapithecus* specimen from Ramnagar (Jammu and Kashmir), India was described and a taxonomic revision of Ramnagar hominoids was carried out. The importance of the study lies in the fact that Hominoids have been known from Ramnagar (Jammu and Kashmir), India since the early part of the 20th century. A number of researchers have intermittently collected vertebrate fossils at Ramnagar resulting in approximately fifteen additional hominoid specimens, most of which are isolated teeth. Over the years, these fossil hominoid specimens have been assigned to a minimum of five genera namely: *Dryopithecus, Sivapithecus, Ramapithecus, Sugrivapithecus* and *Sivasimia* and eight species. There has been little to no historical consensus on Ramnagar hominoid taxonomy, although most recent authorities recognize the Ramnagar specimens as belonging to the genus *Sivapithecus.* In the absence of clear morphological features or extreme size variation indicating the presence of multiple taxa, it is most parsimonious to assume that the recovered hominoid fossils at Ramnagar represent a single species. Supporting this view earlier workers demonstrated that the level of size variation found within the Ramnagar dental sample plus a similarly-aged Chinji Formation-level sample from the Potwar Plateau of Pakistan does not exceed another well-represented and well-supported fossil hominoid taxon from China, Lufengpithecus lufengensis. On this basis, it was argued that all of the Chinji-level fossils from Potwar and Ramnagar are best recognized as a single species with a moderate-to-large degree of variation (mostly attributable to sexual dimorphism), and assigned them to *Sivapithecus indicus* on the basis of taxonomic priority.

A new hominoid specimen (WIF/A 1825) was recovered from a locality near the village of Rashole in the Ramnagar region (Fig. 49), and it was attributed to *Sivapithecus*. The specimen was systematically described and we took an opportunity to 1) provide a working catalog of all published ape specimens from Ramnagar, and 2) perform a series of statistical tests comparing premolar and molar metric variation of the published Ramnagar fossils with the Potwar Plateau Chinji Formation material. For morphological comparison, we compiled data from the literature on premolar and molar dimensions for other large-bodied hominoid specimens from Ramnagar and the Chinji Formation on the Potwar Plateau. In addition, we made qualitative comparisons and collected comparative data on a number of original fossils and casts found at the

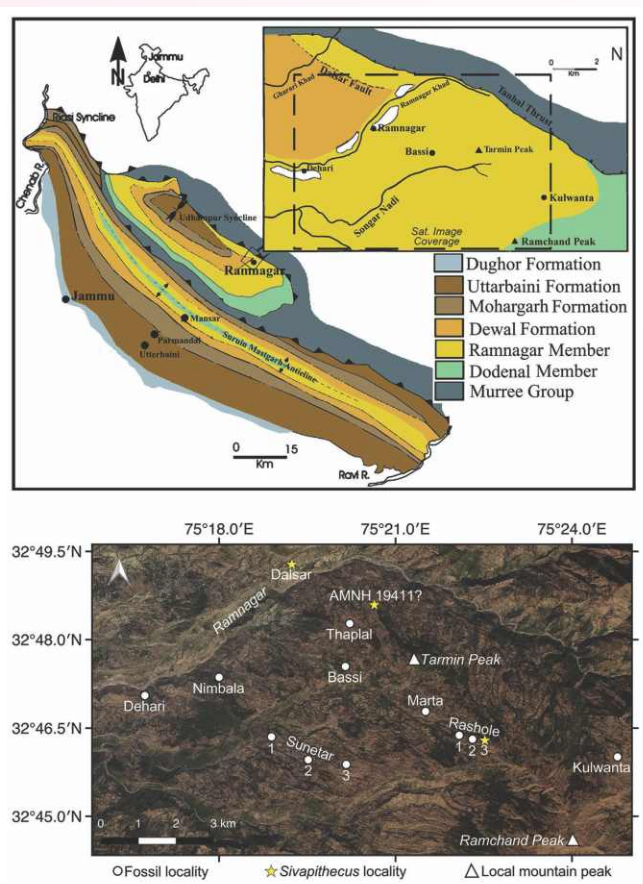

Fig. 49: General geological map of the Siwalik Group surrounding Ramnagar (top) and close-up satellite imagery (GeoEye-1) of the outlined region showing Sivapithecus and non-Sivapithecus-bearing fossil localities (below).

American Museum of Natural History (AMNH) and the Paleoanthropology Laboratory at Harvard University (PLHU). For completeness, in a small number of cases, we took measurements of scaled published photographs using Image J software v.1.45s. All measurements on WIF/A 1825 were obtained with digital calipers. Additionally, the specimen was mCT-scanned for a more detailed morphological study and for digital archiving at the Molecular Imaging Center of the University of Southern California (Los Angeles, USA) using a Nikon Metrology XTH 225ST industrial mCT System. The statistical studies were carried out in collaboration with researchers from the USA.

Simultaneously, a correlative link of the faunas of the Himalayan Foreland Basin with the faunas occurring north of the Himalaya was attempted. It indicated that the dispersal of the mammalian faunas was by and large controlled by the uplift of the Himalaya. During the early Cenozoic, the Himalaya was not a topographic barrier for the migration of the faunas across its width. A large number of the terrestrial genera belonging to the Subathu Group show wide-ranging faunal exchanges between India and central Asia. The faunal assemblages of the Murree/ Dharamshala Group also show significant linkages with the faunas occurring north of the Himalayan arc. The Lower Siwalik faunas (1810 Ma) also show considerable links with contemporaneous faunas from Europe, Africa, and central Asia. However, it was during and after the Nagri Formation of the Siwalik Group (10-8 Ma), the mammalian faunas occurring across the width of the Himalaya show very poor relationships. In the present study, an interpretation of the dispersal patterns of the mammalian faunas, occurring north and south of the Himalaya, during the Cenozoic era, has been carried out to understand its relation to the uplift of the Himalaya. The linkages have been established on the basis of the degree of similarity of the genera, and the preliminary results show that it was during late Miocene (10 to 8 Ma) that Himalaya attained a significant height to act as a formidable barrier for the dispersal of mammalian faunas across its width. The paleontological studies of the Marginal Ganga Plains were carried out and the fossils belonging to Bovidae and *Equus* were identified.

In addition, works have been done on the digital inventory of the fossil collection from the Ramnagar area. This collection was made during the last many years and forms one of the richest collections from the Lower Siwaliks of India. The inventory is being prepared in collaboration with researchers from the USA.

TAT- 5: HIMALAYAN GLACIERS: THEIR ROLE IN INDIAN MONSOON VARIABILITY AND HYDROLOGICAL CHANGES IN THE GANGA BASIN

TAT 5.1
Status of glaciers in Doda and Suru River basins, Ladakh, Western Himalaya

(Manish Mehta, Aparna Shukla and Vinit Kumar)

Under the TAT-5 a project entitled "Status of glaciers in Doda and Suru River basins, Ladakh, Western Himalaya, India" has been formulated for long term monitoring of glaciers in the western Himalaya. This year in order to accomplish the project objectives, relevant field and lab work was carried out to monitor the glaciers in Doda and Suru River basins.

The measurements made on the ablation-stake network suggest that the net balance of the Pensilungpa glacier was negative in 2018-2019. During the measurement periods 2018/19 the net ablation of the glacier was ~ (-) 4.6 x10^6 m^3 we, while the net accumulation of the glacier was ~ (+) 1.49 x10^6 m^3 we. However, the ablation and accumulation gradients of the glacier were ~ (-) 0.120 m/100 m and ~ (+) 0.135 m/100m respectively. Our result also suggested that during the same period the Equilibrium Line Altitude (ELA) of the glacier situated at the height of the 5223 m asl and AAR was 0.43.

The surface ablation is spatially variable, with a maximum value of 3 m in the ablation zone between 4900 and 4950 m a.s.l. and a minimum of 0.2 m near the equilibrium line (5200 to 5250 m a.s.l.) (Fig. 50). However, in the lower reaches between 4650 and 4750 m a.s.l., the average thickness change is 1.8 m (Fig. 50). Usually, it is expected that melting and thus thinning would be more pronounced in the lower elevation, however, the inverse trend (low thinning in lower elevation) could be due to the thick debris-cover.

In order to examine the terminus retreat and area loss of the Pensilungpa glacier during the period

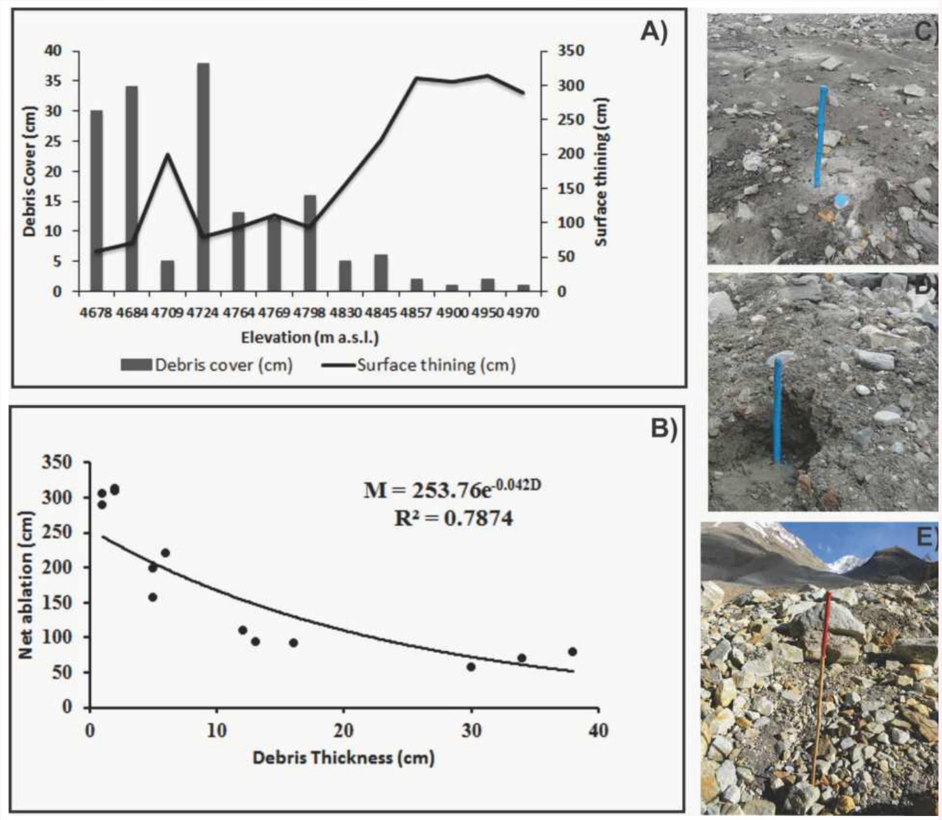

Fig. 50: (A) Relationship between debris thickness and ice melting along the center line of Pensilungpa Glacier (up to 5000 m a.s.l.) during observation periods between 2016 and 2017. (B) Relationship between debris thickness and annual melting, (C,D,E) stake installed over the thin, thick and patchy debris cover.

between LIA and 2019. The measurements were categorized in three time periods (i) total terminal retreat from LIA to 1971 was ~2671 ±48 m at an average rate of 5.9 ±0.1 m a^{-1} (ii) between 1971 and 2017 the glacier receded ~260 ±24 m at an average rate of 5.65 ±0.6 m a^{-1} and (iii) field observations from 2015 to 2019 show that the glacier retreated ~27 ±11.5 m at an average rate of 6.7 ±3 m a^{-1}. Field evidences also reveal that the collapse of an ice cave formed at the right part of the glacier snout which was seen in 2015 but was absent 2019 could be a probable reason behind the enhanced retreat of the right flank. Meanwhile, the google earth images between 2004 and 2019 show the glacier receded ~110.5 ±18.25 m with a rate of 7.4 ±1.23 m a^{-1} (Fig. 51). The total cumulative retreat from LIA and 2019 was ~2941 ±75 with a rate of 5.8 ±0.14 m a^{-1}.

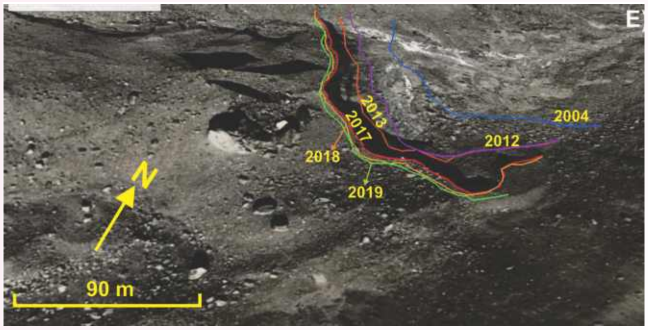

Fig. 51: Google earth image showing the glacier recession between 2004 and 2019.

However, the result of field-based data shows that the snout of the Parkachik glacier receded by ~23 m; while the Durung Drung glacier retreat ~15 m during 2018-2019.

Besides, the estimated meltwater discharge of the Parkachik stream for the periods of October and November (2 months), 2018, and May to August (4 months) 2019 (Fig. 52). The volume of water discharged from the glacier during winter (October and November 2018) was estimated to be 17 x10^6 m^3 (3.17 m^3/sec) and during summer 2019 (June to August) volume of water discharged from the glacier was 33 x10^6 m^3 (3.57 m^3/sec).

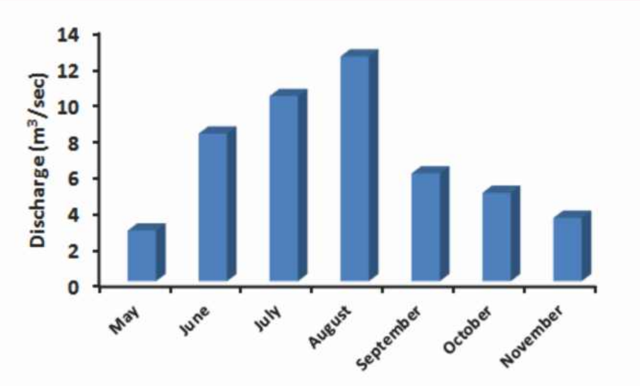

Fig. 52: Month-wise average daily discharge of Parkachik Glacier during the periods of 2018 and 2019.

TAT- 5: HIMALAYAN GLACIERS: THEIR ROLE IN INDIAN MONSOON VARIABILITY AND HYDROLOGICAL CHANGES IN THE GANGA BASIN

SPONSORED PROJECTS

MoES Sponsored Project

Multi-Parametric Geophysical Observatory for Earthquake precursory research at Ghuttu, Garhwal Himalaya

(Naresh Kumar, Gautam Rawat, Devajit Hazarika and P.K.R. Gautam)

Multi-Parametric Geophysical Observatory (MPGO) at Ghuttu, Garhwal Himalaya is established with the main objective of earthquake precursory research in an organized and integrated approach. At this observatory, continuous observations of different geophysical and meteorological parameters are being carried out from more than the last 12 years. Measurements include gravity field based on variation using Superconducting Gravimeter (SG), Geodetic measurements, strong and weak seismic motion, magnetic field, radon concentration, groundwater level, some of the meteorological parameters, i.e. rainfall, atmospheric pressure, atmospheric temperature and temperatures at different depths. The state-of-the-art observatory is situated in the northern end of Lesser Himalaya close to the Main Central Thrust (MCT). In addition, this year in January 2020, soil moisture meters (two units) are also installed to continuously measure moisture in the soil. The data recorded by these soil moisture meters are useful to assess minor hydrological changes in different geophysical time series like gravity variations, rate of radon exhalation, etc. The long-time records of all the data recorded at MPGO, Ghuttu clearly show that each time series has the contribution of many factors in its variations. Aperiodic as well as long and short term periodic trends are reported. Dominant periodic components are annual, seasonal, diurnal, and semi-diurnal changes. Therefore, it is very important to remove these effects to separate the earthquake-induced anomalous variations. In this connection, earlier we have been applied different statistical and analytical approaches like principal component analysis, fractal dimension approach, polarization ratio analysis, FFT analysis, differential plotting, etc. Now, we have analyzed the radon, other meteorological, and hydrological data using multiple regression analysis and singular component decomposition approaches.

Seismic activity in the vicinity of MPGO Ghuttu

To examine anomalous changes due to the occurrences of earthquakes in different data sets, the information of seismic activity in and around the observation site is a pre-requisite. The MPGO Ghuttu located close to the MCT is mainly situated within the Himalayan Seismic Belt where the seismicity is always high and mainly focused in the upper crust. Three-component records of broadband seismograph of the M4.5 earthquake occurred at 145 km distance are shown in figure 53. Detailed information of the low to moderate magnitude

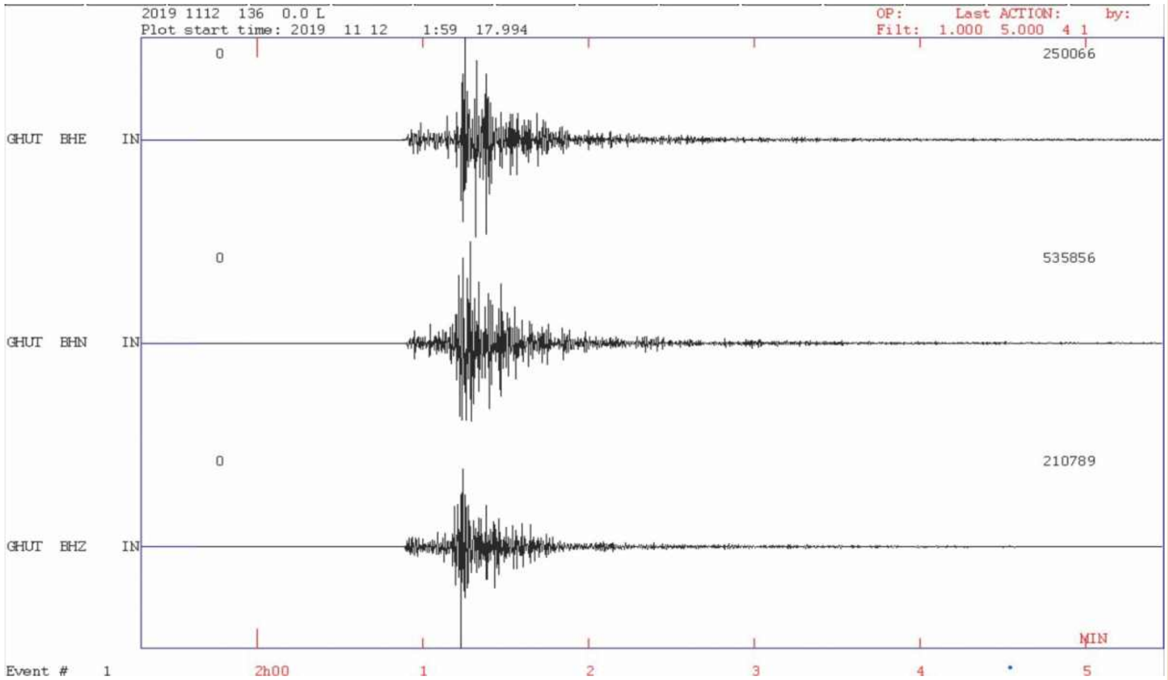

Fig. 53: Three-component seismometer records of the M4.5 earthquake occurred at 156 km distance from MPGO on 12/11/2019.

Table 1: Detail of the earthquakes occurred within 300 km distance from MPGO.

Sl.	Date (mm/dd/yyyy)	Start of recording time (UTC)	Lat. (°N)	Long. (°E)	Depth (km)	Mag.	Epi. Dist. (R) (km)	Seismic Index	D(km)	D/R
1	2/5/2019	10:21:04	32.3	76.4	5	3.2	296.7	0.085	23.768	0.080
2	2/5/2019	14:03:44	31.7	76.8	15	3.8	225.9	0.313	43.053	0.191
3	2/13/2019	2:05:51	32.2	76.4	5	3.5	289.54	0.146	31.989	0.110
4	2/22/2019	1:47:20	31.8	78.2	10	3.5	150.27	0.281	31.989	0.213
5	4/21/2019	15:12:52	30.3	80.4	10	3.5	161.22	0.262	31.989	0.198
6	5/2/2019	23:02:31	31.3	77	10	4.2	186.77	0.756	63.973	0.343
7	5/4/2019	3:07:07	30.9	78.2	10	3.1	66.01	0.320	21.528	0.326
8	6/14/2019	2:22:49	30.4	79.8	10	3.4	102.62	0.346	28.973	0.282
9	7/6/2019	15:30:33	30.7	78.4	5	3.1	37.63	0.561	21.528	0.572
10	7/10/2019	14:25:26	31.4	77.9	10	3.1	125.59	0.168	21.528	0.171
11	7/14/2019	10:12:43	30.9	78.2	10	3	66.01	0.269	19.498	0.295
12	8/23/2019	22:30:30	30.8	78.4	5	3.2	44.26	0.568	23.768	0.537
13	9/11/2019	22:52:22	30.4	79.7	14	3.6	93.14	0.538	35.318	0.379
14	10/1/2019	13:22:38	30.4	79.3	10	3.3	55.58	0.537	26.242	0.472
15	10/14/2019	16:53:04	31.2	77.8	5	3	116.62	0.152	19.498	0.167
16	10/17/2019	15:46:59	31.1	78.7	10	3	63.5	0.280	19.498	0.307
17	10/31/2019	7:14:58	31.5	77	10	3.4	197.8	0.179	28.973	0.146
18	11/12/2019	2:00:27	29.9	80.2	10	4.5	156.8	1.512	86.099	0.549
19	11/24/2019	7:50:12	30.4	79.3	10	3.4	55.58	0.638	28.973	0.521
20	12/8/2019	11:04:17	30.5	79.3	5	3.2	53.75	0.467	23.768	0.442
21	2/4/2020	11:25:19	32.6	78.9	16	3.6	229.59	0.218	35.318	0.154
22	2/8/2020	6:31:47	29.8	80	20	4.7	145.59	2.300	104.954	0.721

earthquakes (M3.0) occurred within 300 km distance is given in table 1 along with seismic index and influencing radius.

The seismic index is calculated for each selected earthquake to assess the effect of the earthquake on the observation point by its size and distance. The seismic index is proportional to the earthquake seismic energy and is computed using formulae (Molchanov et al., 2003):

$$K_s = (1 + R^{-M/2})^{-2.33} \text{ x } 10^{0.75M}/10R \qquad \text{(i)}$$

Where R is the distance from the observation point and M its magnitude.

Also based on the earthquake magnitude and the epicenter distance, the radius of the preparation zone of the earthquake is calculated through the empirical relation by Dobrovolsky *et al.* (1979). The influencing radius in km is given as follow

$$D = 10^{0.43*M} \qquad \text{(ii)}$$

Where D is the influencing radius of the earthquake preparation zone.

Assessment of different components of the borehole and atmospheric data set

Continuous data of different parameters recorded in two different boreholes of 10 m and 68 m depth at two nearby locations (Kopardhar and Dhopardhar) plotted in figure 54 for the period 2019 and 2020. The origin time of earthquakes (M≥3.0) that occurred around MPGO Ghuttu with detailed information in table 1 are marked in figure 54a and b. The seismic index measured using a relation based on the epicenter distance and earthquake magnitude is shown in figure 54a. The size of a red star denotes the magnitude of earthquake events (Fig. 54b) while its y-axes scale represents the epicentral distance from MPGO. The temporal variation of radon emanation in the soil is shown in figure 54c. The other meteorological and hydrological parameters like the level of the water table, rainfall precipitation, subsurface temperature measured at different depths within the borehole, atmospheric temperature, and atmospheric pressure, etc. are also plotted simultaneously in the figure 54.

A high variation in radon emanation is observed during the monsoon period which indicates a high hydrological effect. The data of the remaining period shows comparatively less temporal changes. From July to August high rainfall precipitation adds water within the uppermost crust and therefore charging the groundwater table. Therefore, high fluctuation along with enhancement in water level is observed. The sub-surface temperature at 10 m, 30 m, and 50 m depths remains almost constant and again with some changes

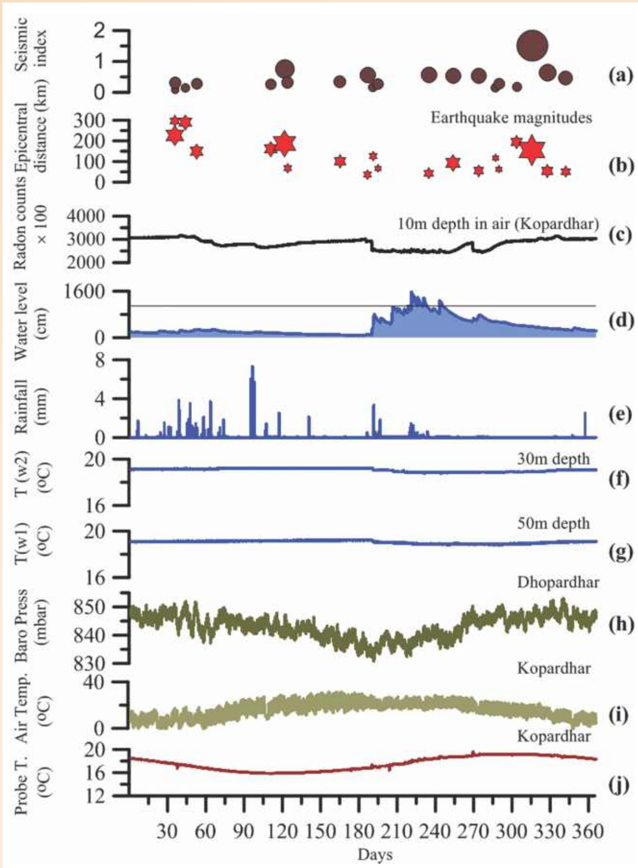

Fig. 54: Plots of the borehole time series of 2019 along with earthquake information. (a) seismic index (b) earthquake epicenter distance and magnitude (c) soil radon (d) water level (e) rainfall (f) temperature 30 m depth (g) temperature 50 m depth (h) atm Pressure (i) atm. Temperature (j) temperature 10 m depth.

during the monsoon period. Atmospheric temperature and atmospheric pressure have high daily fluctuations interlinked with each other and influenced by solar radiation. These two parameters also show annual and seasonal variations. To eliminate these effects from the soil radon data we applied the multiple linear regression analysis and derived modeled values of soil radon. For computing the parameters of the model, first a linear regression analysis is performed among all the parameters including radon, water level, atmospheric pressure, atmospheric temperature, the temperature at 10 m depth, and rainfall. This step is also important for checking the co-linearity among independent variables. First, we selected two independent parameters which have a maximum effect on the radon data. Therefore, we prepared a model using these two independent variables, i.e. water level and atmospheric pressure, and one dependent variable radon for the year 2011 to evaluate the theoretical values of radon exhalation in consecutive years. The obtained year-wise (2011-2019) results are plotted in figure 55. The first panel shows the variation of water level and atmospheric pressure which are used for computing the modeled radon. The variation of observed soil radon at 10 m depth is plotted in the second panel. The variation of residual is plotted in the bottom panel. The analysis removes the hydrological and meteorological effect from the radon data and shows a clear large depletion in the year 2015 which was observed few days before the Gorkha Nepal earthquake (M7.8) of 25 April 2015.

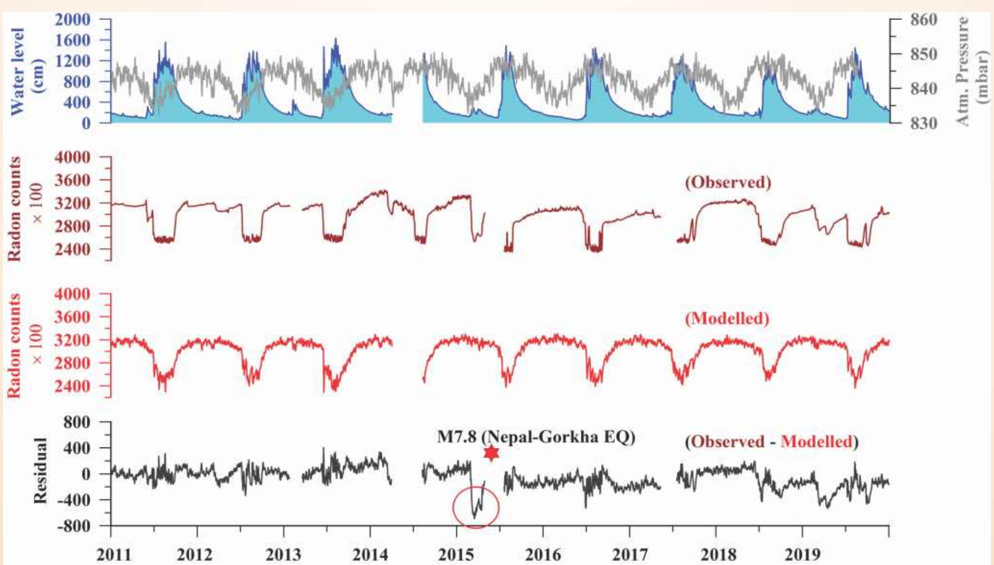

Fig. 55: Year-wise (2011-2019) variation of water level and atmospheric pressure (top panel), observed soil radon at 10m depth (second panel), modeled soil radon using water level, and atmospheric pressure (third panel), the variation of residual (bottom panel).

Gravity data recorded by Superconducting Gravimeter (SG)

Continuous measurement of temporal variation of gravity is performed at MPGO, Ghuttu through superconducting gravimeter. Highly sensitive gravimeter records variations to the microgal level. Although, the instrument was restarted on 29 January 2019 after its repairing work, even then, till date we have recorded high-resolution gravity data of over nine years. The data is processed to evaluate temporal changes in gravity indicating the influence of tidal forces, atmospheric pressure, and hydrological effect. At this site, the tidal forces insert maximum gravity changes to the order of 300 microgal. Changes due to the atmospheric pressure admittance is 3.3 mbar/(nm/s^2). These terms and already adopted methodologies are applied to eliminate this orderly daily and seasonal trends of external fields from the recorded gravity data. De-trend residual gravity data indicates annual variations of the order of 300 nm/s^2 and some abrupt changes of low amplitude. These changes are mostly related to the hydrological effect due to the charging and discharging of the groundwater level with the occurrence of rainfall. The annual variations are well correlated with the changes in the water level observed using an underground water level monitoring probe in a 68 m deep borehole (Fig. 56)

Temporal variation in Electromagnetic Field

The varied methodology is adapted for discriminating lithospheric and ionospheric EM signals to identify precursory signature in the geomagnetic field, ULF band variations, and total intensity measurements. Evolution of fractal dimensional variation ULF band geomagnetic data sets are continuously monitored for distinguishing varied dimensional components associated with distant EM waves resulting from solar wind-magnetospheric interactions and those from near-surface waves emanating from the straining of crustal rocks. Whereas polarization analysis in different frequency bands for ULF and three-component fluxgate data sets are being routinely investigated for identifying the lithospheric origin of anomalies. This year ULF, DFM, and over Hauser magnetometer were reinstated after recalibration of sensors and repair of certain units.

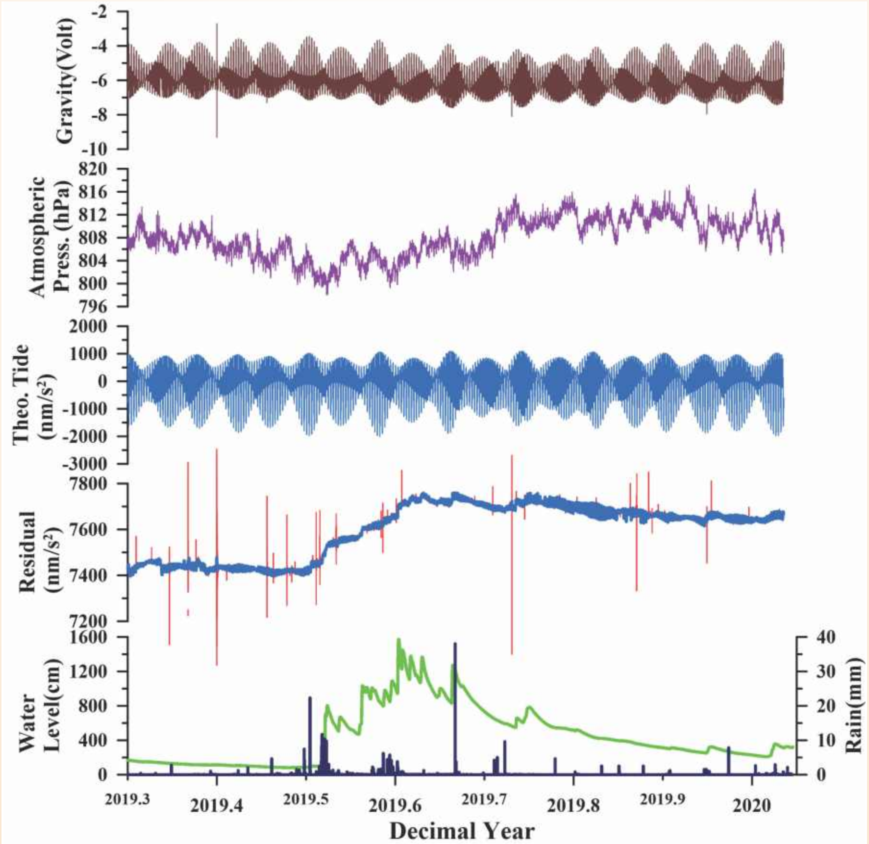

Fig. 56: Temporal variation of gravity observed through Superconducting Gravimeter. (a) Raw gravity data in volts (b) Theoretical solid earth tides (c) atmospheric pressure (d) gravity residual after removing solid earth tide and atmospheric pressure effects (e) Rainfall and water level variations in 68 m borehole.

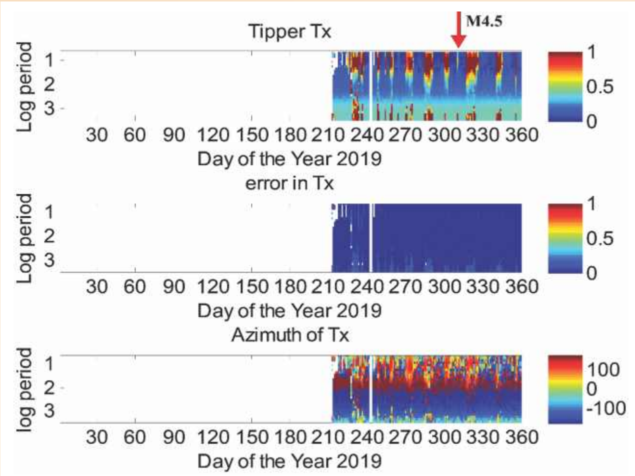

Fig. 57: Daily Tipper (Tx) variation for the period band of 10 s-100 s.

Temporal variation of EM transfer function (Fig. 57) calculated from the variations recorded using a three-component digital fluxgate magnetometer is analyzed. These variations were studied in reference to the earthquakes that occurred around the MPGO observatory.

Geodetic deformation and hydrological in the IGP

The permanent GPS station of MPGO has long continuous records since its installation in 2007. This data has established a highly accurate reference point now suggesting well-defined deformation with reference to Indian or Asian tectonic plates. Its data is also used with local and regional GPS networks to assess the geodetic deformation for different applications. We analyzed the data of our existed CORS network in the Himalaya along with IGS sites. Evidences of active deformation and strain accumulation provide a long term prediction for a future great and major earthquake in the Garhwal-Kumaon Himalayan region. The Main Himalayan Thrust (MHT) in the frontal part of the Himalaya under the Outer and southern part of the Lesser Himalaya is strongly coupled for a width of ~85 km across the Himalayan arc. Strain accumulation in this region is occurring corresponding to a slip deficit rate of 18 mm/year.

The India-Eurasia collision, driven by tectonic forcing, is modulated by nontectonic forcing allied to seasonal variations in the neighboring regions. To decipher the ground deformation in response to hydrological mass variations of the Himalaya and North India, we analyzed continuous Global Positioning System (GPS) observations from 50 sites together with Gravity Recovery and Climate Experiment (GRACE) data for the period 2004-2015 (Fig. 58) (Saji et al. 2020).

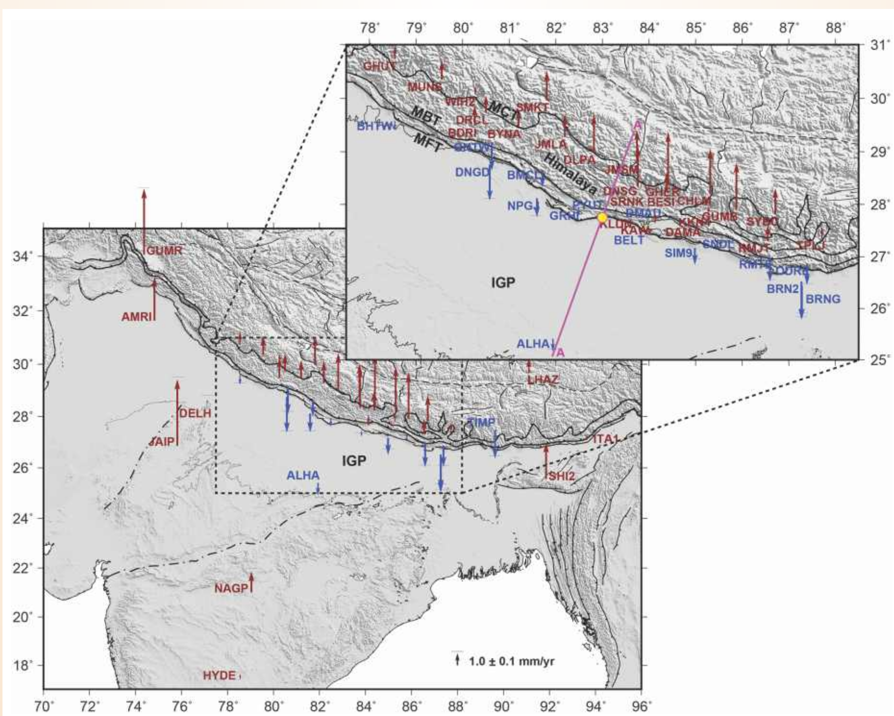

Fig. 58: GRACE corrected secular trend of vertical (vectors) velocities of GPS sites in ITRF-2008. The brown and blue arrows indicate uplift and subsidence, respectively. The inset figure represents the zoomed portion of the IGP and Central Himalaya. The magenta color profile line (A-A′) represents the fault perpendicular profile considered for the projection of vertical velocities. The yellow circle indicates the starting location of the MHT, where it is dipping toward the north.

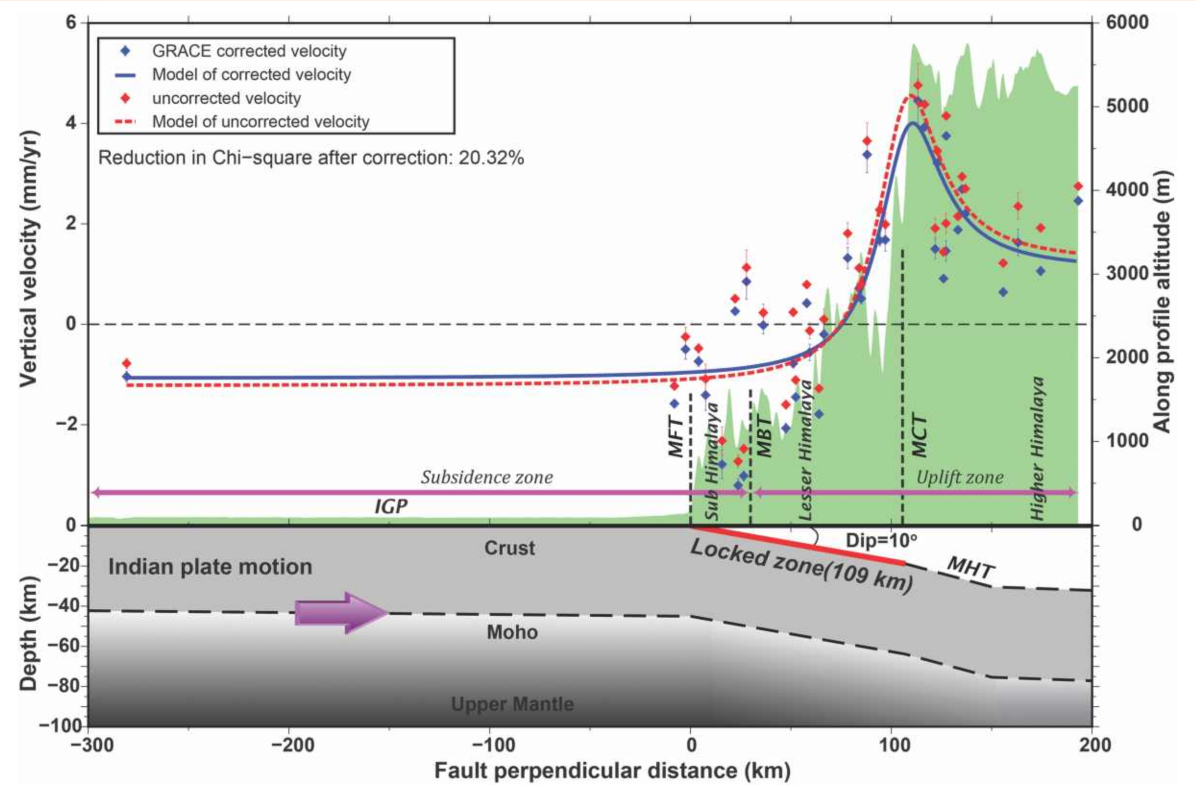

Fig. 59: Cross sectional view of the observed and modelled GPS vertical rates before (red) and after (blue) GRACE correction (please refer to Fig. 58 for profile location). The bottom panel depicts the schematic representation of the underthrusting of the Indian plate across MHT with an assumed dip angle of 10° and an estimated locking width of 109 km from MFT.

Vertical components of surface deformation derived from GPS and GRACE show moderate to high level amplitude correlation with a slope value of 0.76 and a level of phase delay from ±25° to ±30°. The average Weighted Root-Mean-Square (WRMS) reduction of 17.72% suggests the prominence of hydrological mass variations particularly over the sub-Himalayan and Indo Gangetic Plain (IGP). GPS-derived vertical deformation after correcting the hydrological effects utilizing GRACE observations suggests that the sub-Himalaya and IGP are undergoing subsidence and the surrounding areas show uplift. In addition to tectonic and nontectonic driving, unsustainable consumption of groundwater associated with irrigation and other anthropogenic uses influence the subsidence rate in the IGP and sub-Himalaya (Fig. 59).

DST Sponsored Project

Centre for Glaciology

(Director-WIHG, D.P. Dobhal, Rakesh Bhambri, Indira Karakoti, Amit Kumar, Akshaya Verma, R.S. Ahluwalia and Nilendu Singh)

The Centre for Glaciology (CFG) was established at Wadia Institute of Himalayan Geology (WIHG), Dehradun in the year 2009. Since its inception, the CFG has trained manpower in the field of glaciology and has initiated long-term monitoring over nine (09) glaciers including Gangotri, Dokriani, Chorabari, Dunagiri, Bangni, Pindari, Kafni, Panchinala and Patsio glaciers. At present, CFG has expertise in various aspects of glaciology and cryosphere including mass balance, meteorology, hydrology, hydrochemistry, remote sensing, palaeoclimate, atmospheric and environmental sciences, etc. However, the hydrometeorological observations at some of these glaciers were not initiated during 2019-2020.

Some of the key works carried out during 2019-2020 are the following:

Ice-dams, outburst floods, and movement heterogeneity of glaciers, Karakoram

The study concerns ice dams and glacial lake outburst floods (GLOFs) in the Karakoram. Some 146 events are identified, including 30 major disasters (Fig. 60). Large downstream populations and major infrastructure are threatened. Risk factors differ from recent reports of other Himalayan GLOFs associated with glacier recession and global warming. Ice dams are largely or

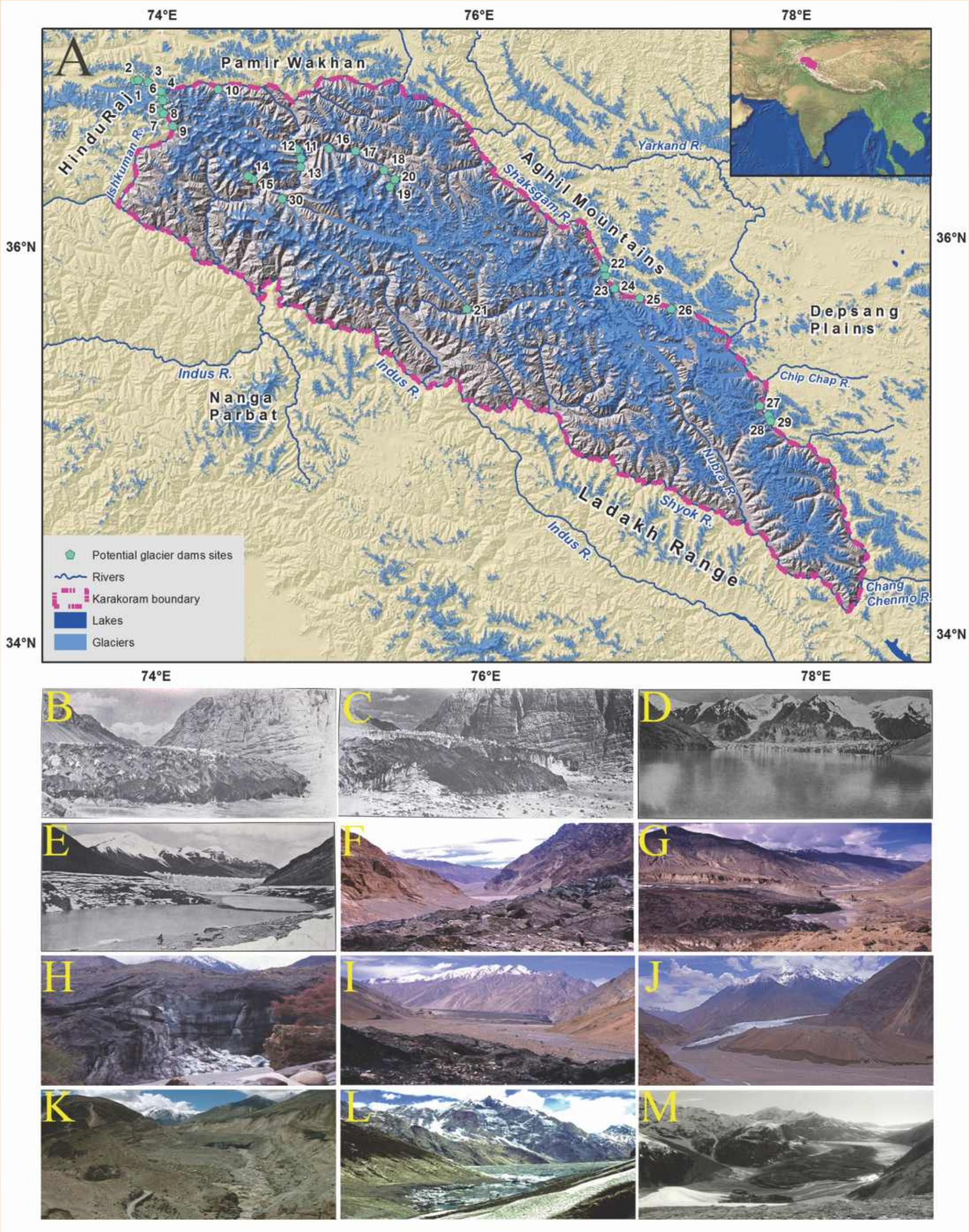

Fig. 60: An overview map of the study area and ice dams. (A) Location of the Ice dams in the Karakoram and neighbouring ranges. (B) Terminus of Chong Kumdan Glacier (ID 27) in 1929 from downstream before the ice dam broke. (C) Terminus of Chong Kumdan (ID 27) Glacier in 1929 from downstream after the ice dam broke. (D) The Chong Kumdan (ID 27) Ice dam from the lake on 12th August 1929. (E) The Kyagar (ID 26) Glacier Ice dam across the Shaksgam Valley in 1926. (F) Site of Khurdopin Glacier (ID 20) Ice dam across the mouth of Virjerab valley in 2000. (G) Malangutti Glacier (ID 17) advancing across the Shimshal River in 2000. (H) Malangutti (ID 17) ice advancing into the Shimshal River. (I) East flank lobe of Yazghil Glacier (ID 18) advancing to the opposing valley wall, blocking the Shimshal River but not impounding a lake. (J) West flank lobes of Yazghil Glacier (ID 18). (K) Bualtar Glacier (ID 30) advancing towards the junction with Hispar River in the right foreground, site of historic and prehistoric ice dams. (L) Views of Chhatteboi-Karamabar (ID 3) ice dam site. Looking southeast and downstream from the small lake on the Karambar River. (M) Looking northwest and up-valley over the terminal lobe of Chhatteboi-Karamabar Glacier. Sub figs. (B–E) published with the permission of the Himalayan Journal.

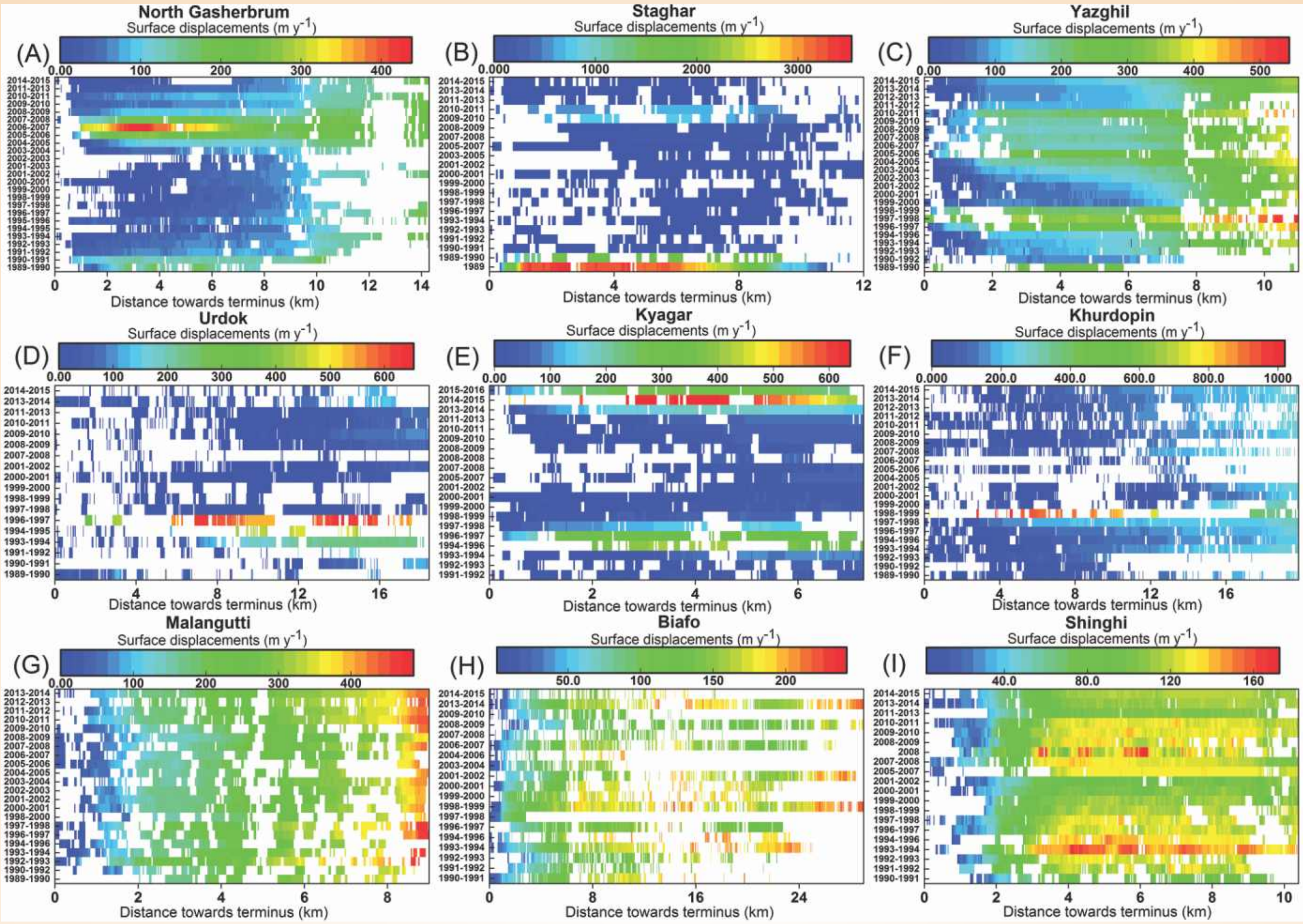

Fig. 61: Surface displacement of nine Karakoram glaciers from the 1990s to 2015-16. (A) North- Gasherbrum (ID 22), (B) Staghar (ID 24), (C) Yazghil (ID 18), (D) Urdok (ID 23), (E) Kyagar (ID 26), (F) Khurdopin (ID 20), (G) Malangutti (ID 17), (H) Biafo (ID 21) and (I) Shinghi (ID 25). Surface displacement generated using Image correlation software (CIAS) (Kääb and Vollmer, 2000). Satellite image pairs and used for automated feature tracking including the estimated uncertainty. The location of surface displacement of these glaciers in the Karakoram is presented in figure 60 (glacier ID).

entirely active ice, put in place by advancing glaciers. Climate change is a factor, but the ice cover in the Karakoram has been sustained, and even some increase in mass. Surge-type glaciers comprise or affect~70% of our inventory. The most frequent, large GLOFs come from local clusters of glaciers in five sub-basins, given special attention here. In four there were new ice dams formed since 2008 and two generated dangerous GLOFs. An urgent need arises to track short-term ice and lake behavior and how surge dynamics may be involved. Satellite images and DEMs are employed in cross-correlation feature tracking and elevation change respectively. The glaciers of interest all exhibit irregular movement, including recent advances, but with great variability and no clear relation to climatic fluctuations (Fig. 61).

Topographic and climatic influence on seasonal snow cover: implications for the hydrology of ungauged Himalayan basins, India

Himalayan glaciers exert considerable influence on basin hydrology and its response to climate change. Meltrunoff generated from ungauged Himalayan basins (UHB) requires an understanding of snow and ice cover extent along with prevailing meteorological conditions. Therefore, an estimation of seasonal snow cover distribution, topographic (elevation, aspect, and slope) and climatic variability was carried out using satellite data and meteorological observations from three automatic weather stations (AWSs) located at different elevations in a UHB (i.e. Chorabari Glacier). Results suggest that the topography and the meteorological conditions of the basin influence the dynamics of snow cover and the corresponding processes responsible for the melt-runoff generation. The snow cover area (SCA) has high variability in the elevation range of 3799-5000 m, indicating that as glacier ablation begins, SCA below this elevation primarily contributes to the melt-runoff. Likewise, the eastern aspect and the slopes (010° and 7080°) show higher variability. Further, the annual distribution of air temperature gradients (dT/dZ) or temperature lapse rates (TLRs) exhibits a bimodal pattern (Fig. 62). The mean annual TLR for the basin is 6.0 °C km^{-1}, which is lower than the traditionally used adiabatic or environmental lapse rate (6.5 °C km^{-1}). We also established the role of TLRs in the dynamics of SCA, which is an important parameter used for the computation of melt-runoff. The 0°C isotherm established indicates that the elevation zone above 5000-5500 m has persistent snow cover throughout the year and snow cover below this zone contributes to the melt-runoff during the ablation season (Fig. 63). Therefore, validating the equilibrium line altitude

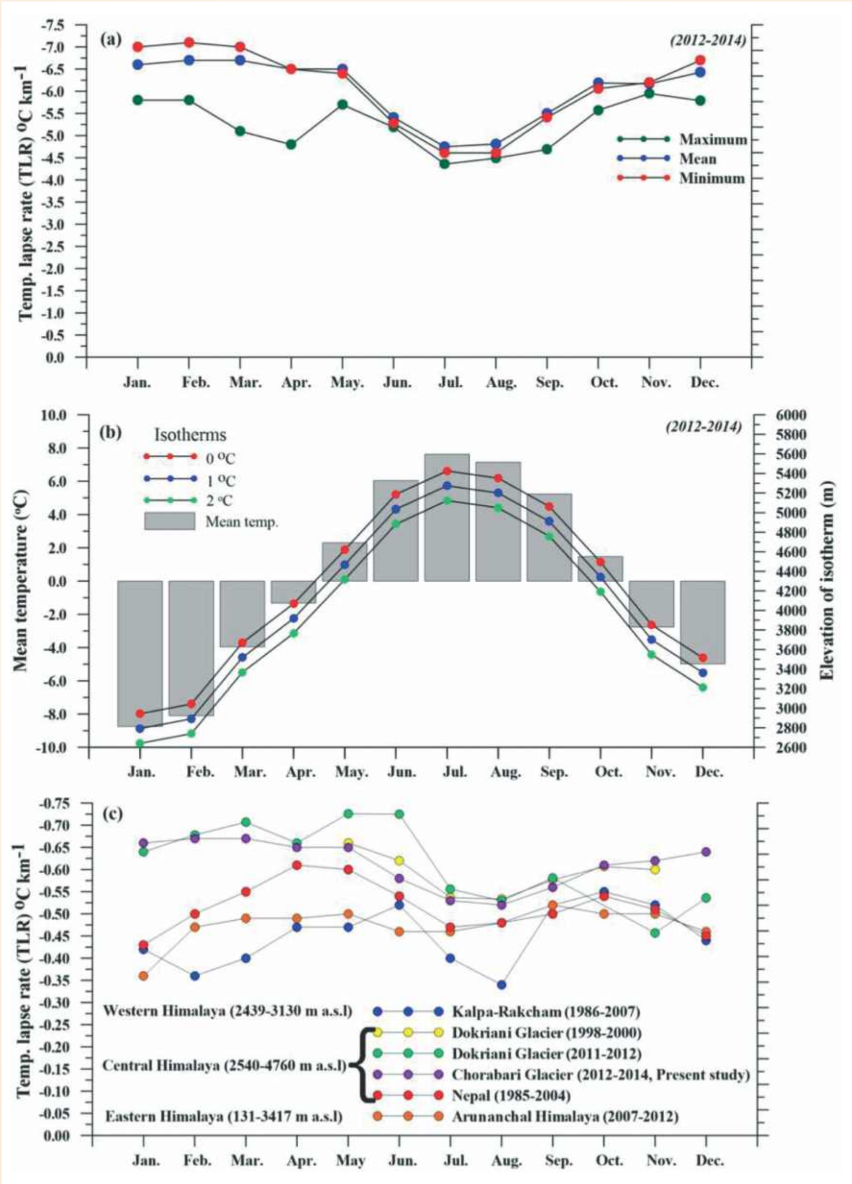

Fig. 62: (a) Monthly distribution of temperature lapse rates (TLRs) for maximum (Tmax), minimum (Tmin), and mean (Tmean), temperatures; (b) distribution of monthly mean air temperature (Tmean) along with the elevation of different isotherms constructed over Chorabari glacierized basin; and (c) comparison of TLR (Tmean) in the present study with different studies in IHR (Western Himalaya, Thayyen and Dimri, 2018; Central Himalaya, Thayyen et al., 2005; Kattlel et al., 2013; Pratap et al., 2013; and Eastern Himalaya, Bandyopadhyay et al., 2014).

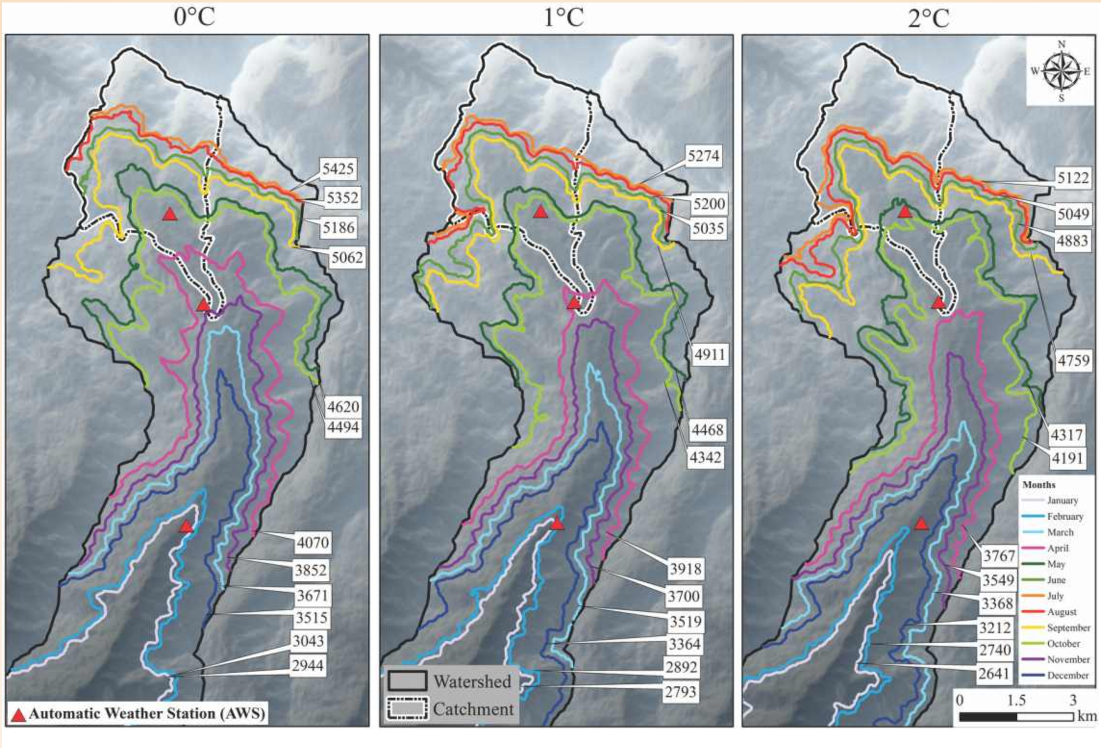

Fig. 63: Delineation of mean monthly isotherm (0, 1, and 2°C) elevations using observed temperature lapse rates over Chorabari glacierized basin for the years 2012-2014.

(ELA) of Chorabari Glacier lies within this zone. Since the TLR and SCA vary with space and time, our study in an ungauged glacierized basin of river Ganga could be useful for policymakers as well as other researchers working on the regional hydrology.

The hazardous 2017-2019 surge and river damming by Shispare Glacier, Karakoram

In 2017-2019 a surge of Shispare Glacier, a former tributary of the once larger Hasanabad Glacier (Hunza region), dammed the proglacial river of Muchuhar Glacier, which formed an ice-dammed lake and generated a small Glacial Lake Outburst Flood (GLOF). Surge movement produced the highest recorded Karakoram glacier surface flow rate using feature tracking (~18 ± 0.5 m d^{-1}) and resulted in a glacier frontal advance of 1495 ± 47 m. The surge speed was less than reports of earlier Hasanabad advances during 1892/93 (9.3 km) and 1903 (9.7 km). Surges also occurred in 1973 and 2000-2001. Recent surges and lake evolution are examined using feature tracking in satellite images (1990-2019), DEM differencing (1973-2019), and thermal satellite data (2000-2019) (Fig. 64). The recent active phase of the Shispare surge began in April 2018, showed two surface flow maxima in June 2018 and May 2019, and terminated following a GLOF on 22-23 June 2019 (Fig. 65). The surge likely had hydrological controls influenced in winter by compromised subglacial flow and low meltwater production. It terminated during summer probably because increased meltwater restored efficient channelized flow. We also identify considerable heterogeneity of movement, including spring/summer accelerations.

Late-Holocene climate response and glacial fluctuations revealed by the sediment record of the monsoon-dominated Chorabari Lake, Central Himalaya

We studied a periglacial lake situated in the monsoon-dominated Central Himalaya where an interplay of monsoonal precipitation and glacial fluctuations during the late Holocene is well preserved. A major catastrophe occurred on 1617 June 2013, with heavy rains causing rupturing of the moraine-dammed Chorabari Lake located in the Mandakini basin, Central Himalaya, and exposed 8-m-thick section of the lacustrine strata. We reconstructed the late-Holocene climatic variability in the region using a multi-parametric approach including magnetic, mineralogical, and chemical (XRF)

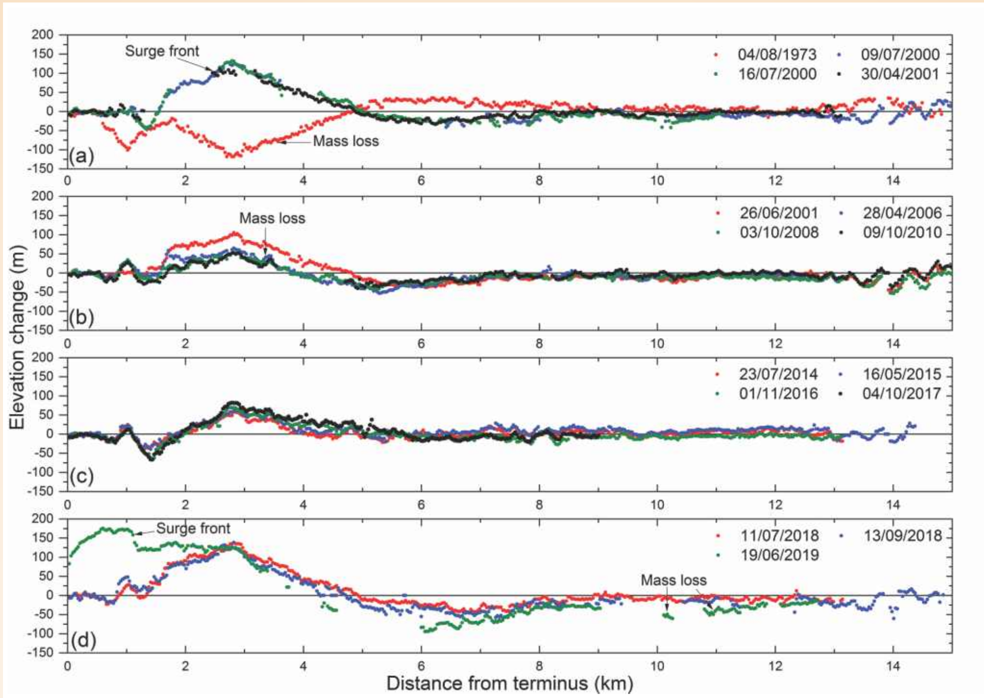

Fig. 64: Elevation change of Shispare Glacier using KH-9 Hexagon, multiple ASTER and the SRTM DEMs. The KH-9 Hexagon and ASTER DEMs (dates presented in the legend) were subtracted from the reference SRTM DEM to compute elevation changes.

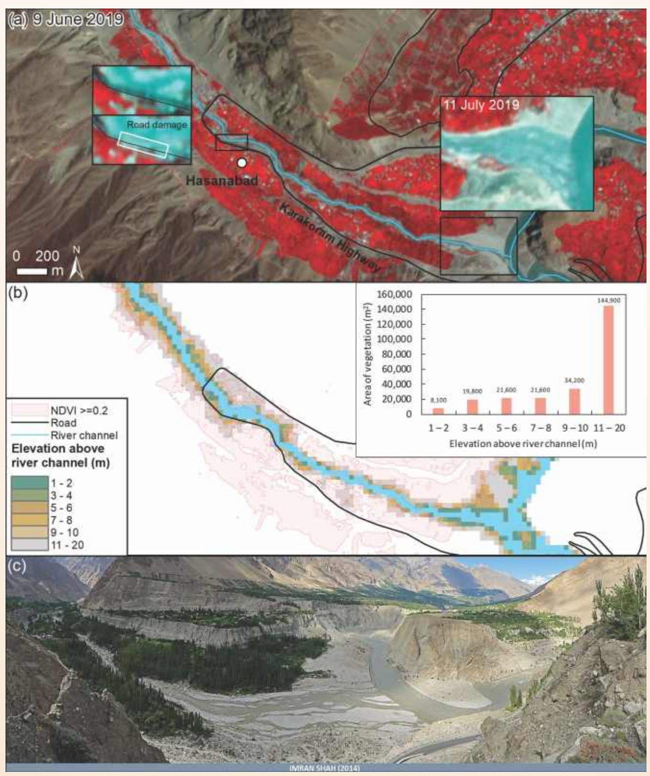

Fig. 65: PlanetScope image (09 June 2019) of the river channel and adjacent vegetated land (agricultural fields, tree plantations and orchards) before lake drainage, with post-lake drainage insets (11 July 2019). (b) Elevation above the river channel and the area of vegetated land (09 June 2019) within each elevation band. (c) Panoramic view in 2014 of the confluence with the Hunza River, overlooking the inset in panel (a) (Photograph by Imran Shah. 2014. License: CC BY-SA 2.0).

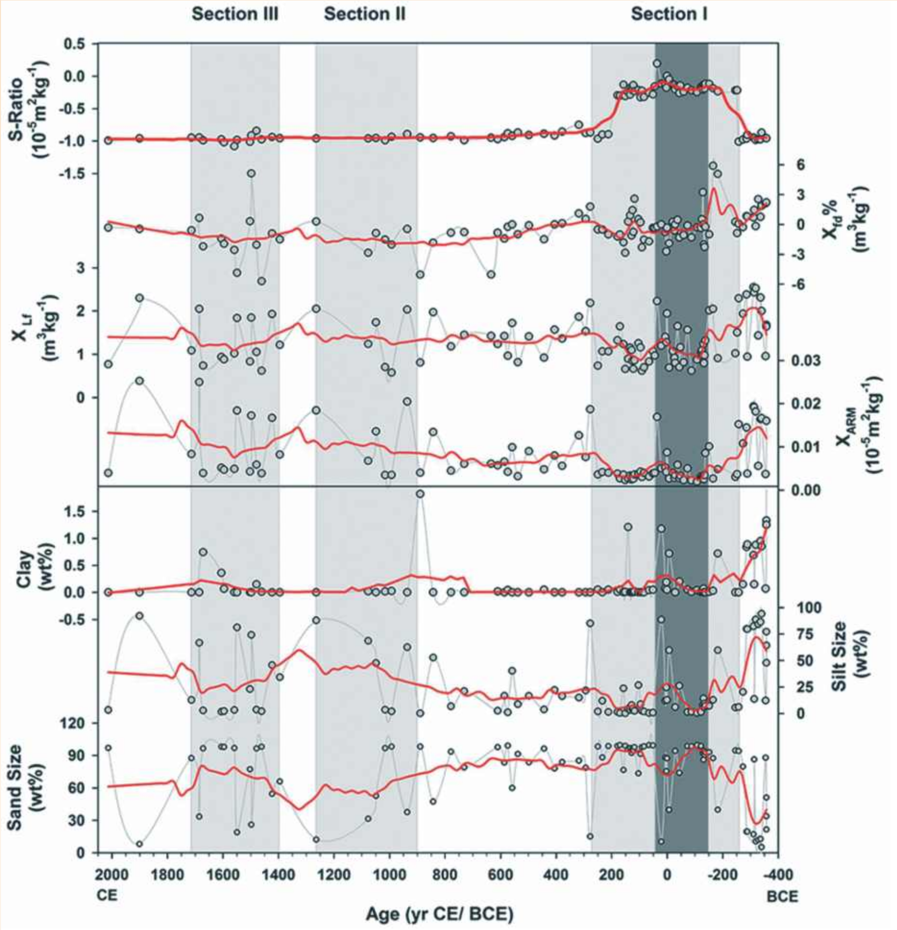

Fig. 66: Environmental magnetism and grain size proxies plotted against lake chronology. The shaded part indicates different sediment deposition patterns with respective climatic conditions at the lake for a specific time period. The mean climate state of representative proxy response is marked in red and calculated with 2D smoothening of the data using sigma plot software version 14.

properties of sediments, paired with grain size (Fig. 66) and optically stimulated luminescence (OSL) dating (Fig. 67). The OSL chronology suggests that the lake was formed by a lateral moraine during the deglaciation phase of Chorabari Glacier between 4.2 and 3.9 ka and thereafter the lake deposited about 8-m-thick sediment sequence in the past 2.3 ka. The climatic reconstruction of the lake broadly represents the late-Holocene glacial chronology of the Central Himalaya coupled with many short-term climatic perturbations recorded at a peri-glacial lake setting. The major climatic phases inferred from the study suggests (1) a cold period between 260 BCE and 270 CE, (2) warmer conditions between 900 and 1260 CE for glacial recession and (3) glacial conditions between ~1370 and 1720 CE when the glacier gained volume probably during the 'Little Ice Age' (LIA). We suggest a high glacial sensitivity to climatic variability in the monsoon-dominated region of the Himalaya.

Natural versus anthropogenic influence on trace elemental concentration in precipitation at Dokriani Glacier, central Himalaya, India

Atmospheric pollutant transport and deposition at the Himalaya affect the climate, cryosphere, and monsoon patterns and impose an adverse impact on the Himalayan ecosystem. At present, the data on trace elements (TEs) concentrations and dynamics over the high-altitude Himalayan region are scarce and have received less attention. Therefore, in the present study, we investigated the TEs concentration and depositional pattern at Dokriani Glacier, central Himalaya to understand their levels, dynamics, and potential effects. A total of 39 samples were collected from two snowpit stratigraphies, deposited during non-monsoon period and monsoonal precipitation between 4530 to 4630 m a.s.l. altitude in the year 2017. The results of analyzed trace metals (Al, Cr, Mn, Fe, Sr, Co, Ni, Cu, Zn, Cd, As,

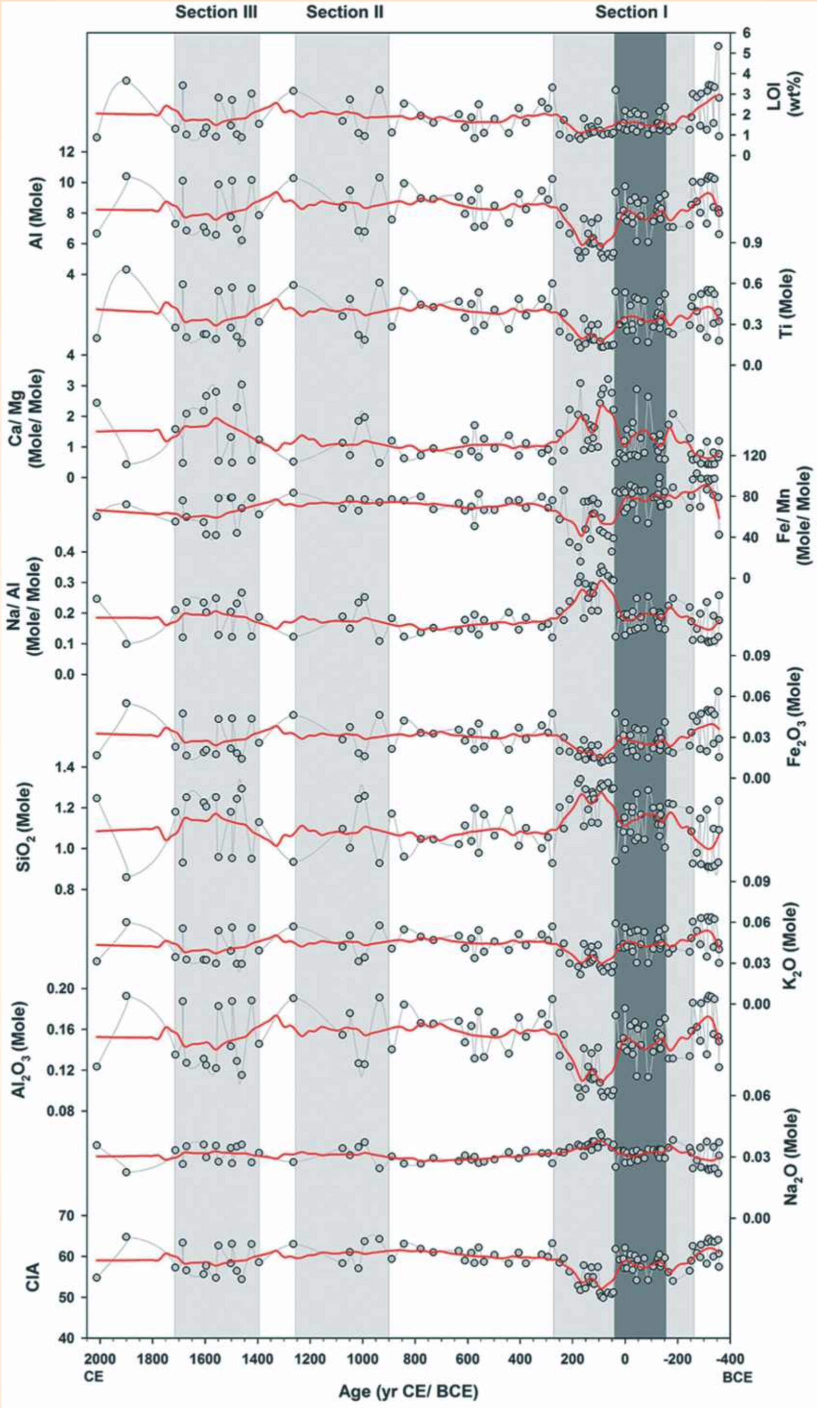

Fig. 67: Geochemical proxies plotted against lake chronology. The shaded part indicates different sediment deposition patterns with respective climatic conditions at the lake in a specific time interval. The mean climate state of representative proxy response is marked in red and calculated with 2D smoothening of the data using sigma plot software version 14.

and Pb) showed high enrichment values for Zn, Cr, Co, Ni and Mn compared to other parts of the Himalayan region, suggesting the influence of anthropogenic emissions (e.g., fossil fuel, metal production, and industrial processes) from urbanized areas of South Asia (Fig. 68). Our results also revealed the possible health effects related to the enrichment of Zn and Cd, which may be responsible for skin-related diseases in the Uttarakhand region. We attribute increasing anthropogenic activities in the environment to have a

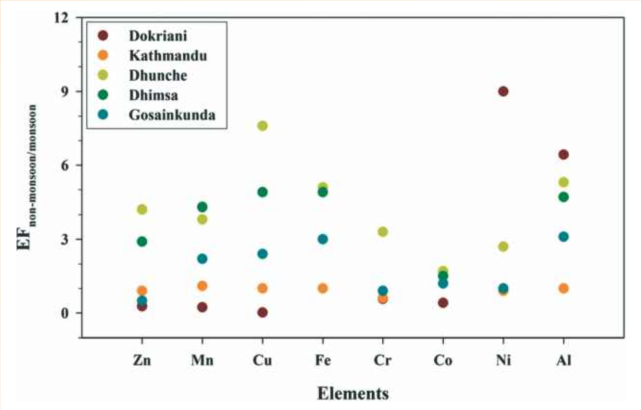

Fig. 68: Comparison of ratios of elemental concentrations between non-monsoon and monsoon at Dokriani Glacier with other parts of the Himalayan region.

significant impact on the ecosystem health of the central Himalayan region. This study provides the baseline information on TEs concentration and sources in the Himalaya, which needs wide dissemination to the scientific community as well as policymakers. Therefore, systematic observations, management, and preparing an action plan to overcome the health effects from TEs pollution are urgently needed over the remote, pristine Himalayan region.

Radiation and energy balance dynamics over a rapidly receding glacier in the central Himalaya

Driven by the strength in local land-atmosphere coupling, interannual variability of large-scale atmospheric circulations primarily determines a glacier's response to warming in high Asia. In this study, micrometeorological measurements (Fig. 69) in conjunction with regional reanalysis data set were analyzed to examine seasonal land-atmosphere coupling strength at a typical central Himalayan (CH) glacier where the influence of Indian summer monsoon (ISM) predominates relative to winter westerlies. Energy-water (E-W) exchange and coupling behavior were studied for the Pindari glacier based on sub-hourly measurements of radiative-convective flux, state parameters, and sub-surface thermal profiles using cross-correlations between various E-W balance components. Coupling was positive in summer and winter accumulation seasons. However, it remained strongest during ISM. Coupling reversed during seasonal transition phases concurrent with distinct seasonality in E-W components.

Fig. 69: The multi-level sensors installed on a 12 m high mast for detailed land-atmosphere interaction and micrometeorological experimentation at the Pindari glacier site.

Lead-lag relation between some variables showed strong association at diurnal-scale (VPD-*R*n; VPDLE; *R*n-*G*), whereas some persisted beyond months (*R*n-LE; Bowen ratioprecipitation; surface-air temperature). A weak association of variation of latent heat flux (LE) and rainfall was found during ISM at a local scale than at the regional scale, but with a lag, which was more prominent at a regional scale. These observations indicate a seasonally variable coupling between E-W balance components through response feedback mechanisms. Cross-correlations of daily mean values of energy fluxes and meteorological variables reveal that *R*n and air temperature are the prime drivers of energy balance. Net radiative energy (*R*n) dominates energy exchanges at the glacieratmosphere interface (governed primarily by the variation in net shortwave radiation), contributed on average 62% of the melt energy. However, sub-surface heat flux along with the turbulent fluxes was the energy sinks of 24 and 15%, respectively. This study would help understand and parameterize E-W exchange pathways for ISM dominated CH glaciers in the coupled glacierclimate models.

Spatio-temporal variability of near-surface air temperature in the Dokriani glacier catchment (DGC), central Himalaya

Air temperature is one of the most important meteorological factors that affect the melting of glaciers, distribution of snowfall, and rain at higher altitudes in the Himalaya. However, studies on Spatio-temporal variability of air temperature in the central Himalaya are limited. In the present study, seasonal and annual characteristics (July 2011 to December 2015) of near-surface temperature and lapse rate in the Dokriani glacier catchment (DGC) of the central Himalaya are investigated using data from three automatic weather stations (AWSs) (Fig. 70). An attempt is also made to quantify 0°C isotherm and temperate sustainability over the glacierized area. The results reveal that the average near-surface temperature lapse rate (NSTLR) of the

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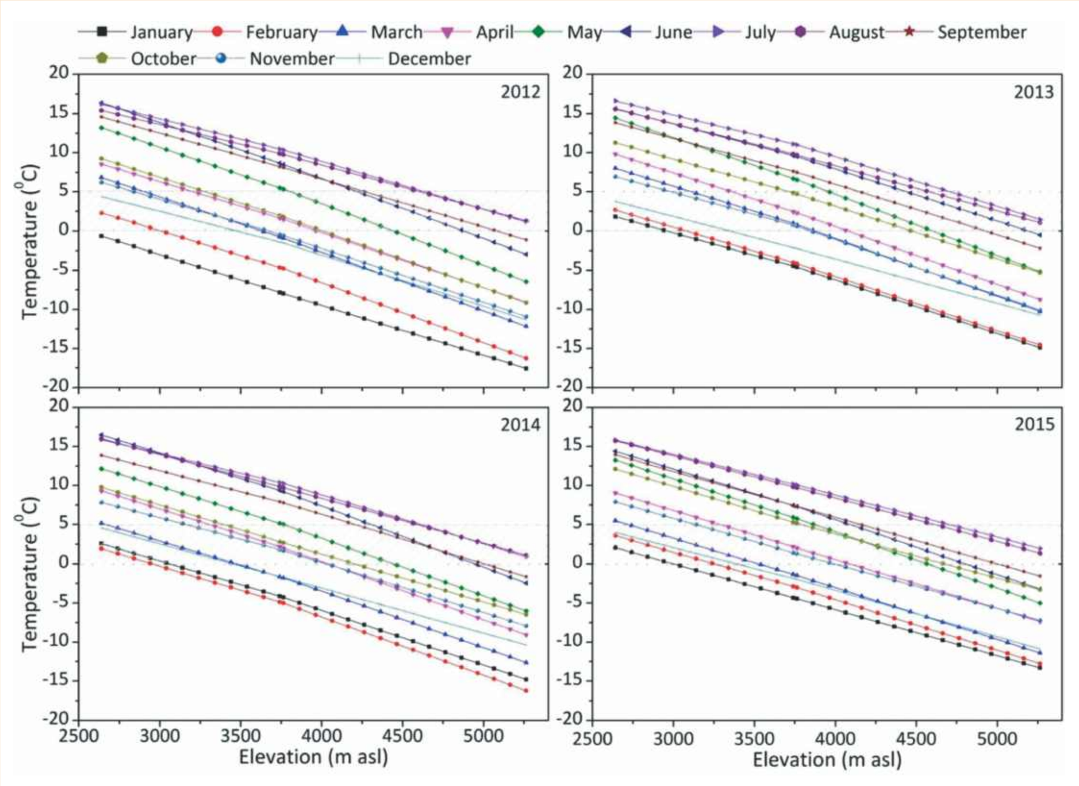

Fig. 70: Graphs showing the temperature variation with elevation in the Dokriani Glacier catchment (2012-2015). The phase change is marked by a gray line pattern between temperature range 0-5 °C.

catchment varies from 4.6 to 7.5 °C km^{-1} during all measurement seasons, suggesting that the standard environmental lapse rate (SELR, 6.5 °C km^{-1}) is not a promising input for realistic glacio-hydrological modeling. The seasonal variability of the NSTLR indicates that the monsoon (warm and humid period) lowers the temperature lapse rate in this catchment due to the presence of high moisture content in the air. The steepest lapse rate is investigated during the pre-monsoon season due to clear and drier weather conditions. In addition to this, the results reveal strong variability in NSTLR at diurnal and sub-diurnal levels, with high variability in the day time and low in the night-time hours. Higher air temperature is examined in the ablation zone of the Dokriani Glacier during the monsoon season (i.e., JJAS: June, July, August, September), while other seasons (pre-monsoon, post-monsoon, winter) show both higher as well as lower temperatures. A large variation in 0 °C isotherm is also observed ranging from 5000 to 5500 m asl during 2012-2015 (Fig. 71). The present work emphasizes that the study of monthly, seasonal, and annual variability of the NSTLR are very important for glacio-hydrological research in the central Himalaya.

Ground monitoring and characteristics of Black Carbon Aerosol over the glacier of central Himalaya: a case study of Dokraini Glacier

Sufficient site-level observations are needed to resolve the discrepancies between *in-situ* and space-based observations for reliable climate mitigation and adaptation strategies. Resolving discrepancies from the understudied Himalaya is a priority for the Indian sub-continent. This study investigates the characteristics and source of black carbon aerosol (BC) over a glacier at the transitional climatic zone between central and western Himalaya (lat/long). BC was measured with an Aethalometer at the highest altitude (4000 m asl) in the Indian Himalaya covering a complete annual cycle (Nov. 2015 - Oct. 2016). Mean daily BC loading varied from 37.5 to 5638.3 ng m^{-3} (mean ± std. dev. = 307.6 ± 292.1 ng m^{-3}), indicating substantial BC burden over the region even at this high tropospheric altitude. BC loadings were highest during the pre-monsoon (1276.4 ± 114.8 ng m^{-3}) and lowest during the monsoon (307.6 ± 37.1 ng m^{-3}), with comparable magnitudes during winter and post-monsoon (400-500 ng m^{-3}) (Fig. 72). Seasonal dynamics are similar to those reported form central Himalaya including that of southeastern Tibet. Pre-monsoonal peaks were coincident with the high

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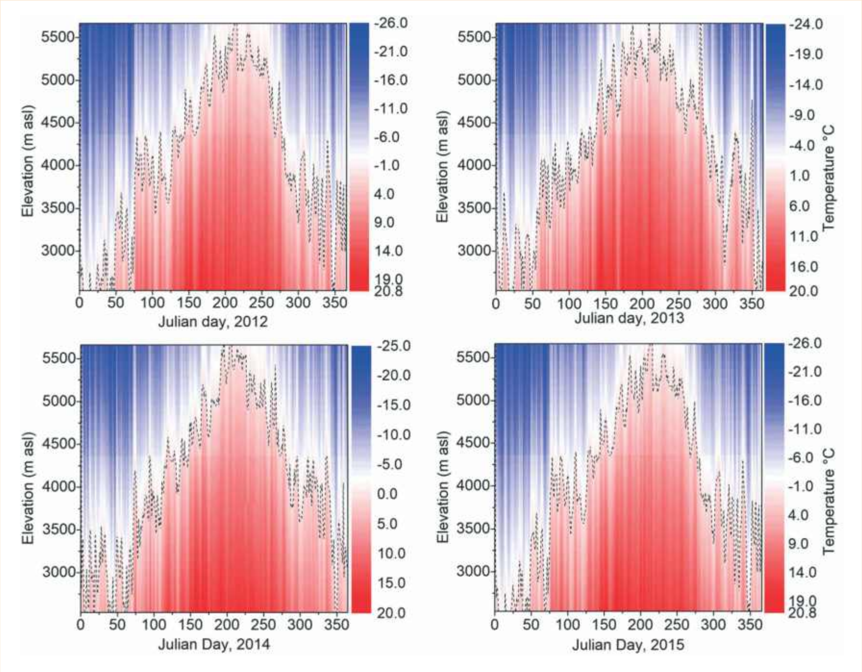

Fig. 71: Extrapolated average daily temperature between 2440 and 5600 m asl using the NSTLR from three AWS's TAvg for the period of 2012-2015. Black dotted line shows zero-degree temperature isotherms (e.g., ZT=0).

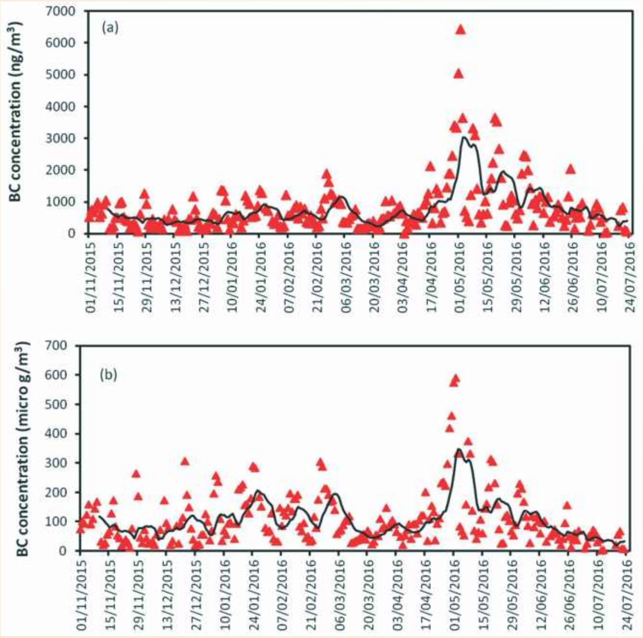

Fig. 72: Variation of BC mass concentration in (a) atmosphere (b) snow, the solid line represents the trend of variation, in snow from November 2015 to July 2016 at Dokraini Glacier valley.

atmospheric boundary layer. Irrespective of the seasons, daily peaks occurred from 14:00 to 18:00 local time, with similar fluctuations at other times. Mean concentration in the surface snow is found to be ~135 µg kg^{-1}, having similar seasonal dynamics, indicating considerable BC burden on snow. Statistical analyses suggest a positive correlation with the state parameters, except precipitation. BC induced annual radiative forcing at atmosphere was +10.1 ± 3.0 Wm^{-2}. These results show that BC concentration at this critical transitional climatic zone has the potential to affect both regional climate and hydro-glaciological resource variability.

Developing a low-cost weather monitoring system for data-sparse regions of the Himalaya

A weather monitoring system has been developed using open-source hardware and software with the main objective being the collection of meteorological data at a very low cost in the remote terrain of the Indian Himalayan region. At present, the most common commercially available automatic weather stations are too expensive and it is not cost-effective to install them at multiple locations simultaneously, resulting in a scarcity of data in many remote areas of the Himalaya. To address this, we used an open-source Arduino microcontroller-board & programmed it in a simple Integrated Development Environment (IDE). Using this device, we validated this system with another calibrated system located at Wadia Institute of Himalayan Geology (WIHG), Dehradun (30.32° N, 78.01° E). A good correlation was found between the data of these two systems (Fig. 73). We have also collected air temperature, Relative Humidity data for 84 days at Kedarnath Temple, which is located at 30.73° N, 79.06°

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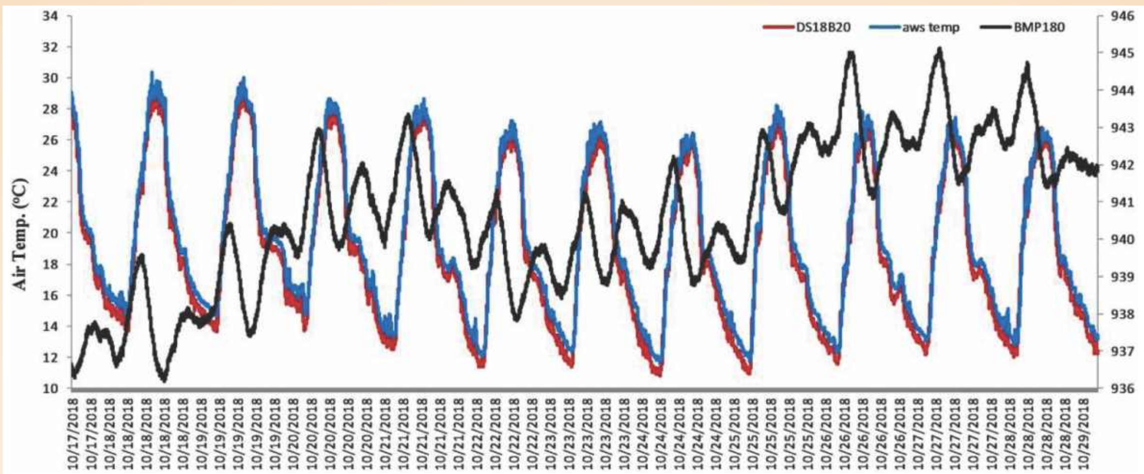

Fig. 73: Time series of temperature and pressure per minute from both sensors at WIHG, DDN.

E in the higher Himalaya (3560 msl). It is to be noted here that this is the first type of low-cost open-source system installed at high altitudes in the Himalaya, India.

On the strongly imbalanced state of glaciers in the Sikkim, eastern Himalaya, India

This study evaluates multiple glacier parameters (length, area, debris cover, snowline altitude (SLA), glacial lakes, velocity, and surface elevation change) to comprehend the response of poorly understood glaciers of the Sikkim Himalaya to climate change. For the proposed task, 23 representative glaciers were selected from the region, and remotely acquired data from Landsat-TM/ETM/OLI (1991-2017), and Terra-ASTER (2007-2017) along with the SRTM DEMs were used for extraction of the various parameters. Results show that during 19912015 the studied glaciers have significantly retreated (17.78 ± 2.06 m a^{-1}), deglaciated ($5.44 \pm 0.87\%$), and experienced a considerable increase in SLA (~7 m a^{-1}) and debris cover ($16.49 \pm 2.96\%$). Glaciers slowed-down (by 24.90%) with sizable growth in number (23.81%) and area ($48.78 \pm 2.23\%$) of glacial lakes. They also exhibit a notable downwasting (-0.77 ± 0.08 m a^{-1}) during 2000-2007/17 (Fig. 74). The behavior of glaciers in the region is heterogeneous and found to be primarily determined by glacier size, debris cover, and glacial lakes. Though a generalized mass loss is observed for both small- (<3 km^2) and large-sized glaciers (>10 km^2), they seem to adopt different mechanisms to cope with the ongoing climatic changes. While the first adjust mostly by retreat/deglaciation, the latter lose mass through downwasting. Comparing with other Himalayan regions, the magnitude of dimensional changes and debris growth is higher in the Sikkim. The SLA trends are comparable with the central and western Himalaya up to 2000, but a reverse trend is seen afterward. Also, contrary to the western and central Himalaya, where glaciers are reported to have slowed down in recent decades, the Sikkim glaciers have shown negligible deceleration after 2000. Climate analysis confirms the almost double increase in summer temperature (24.47%) than winters (12.77%) during 1990-2016,

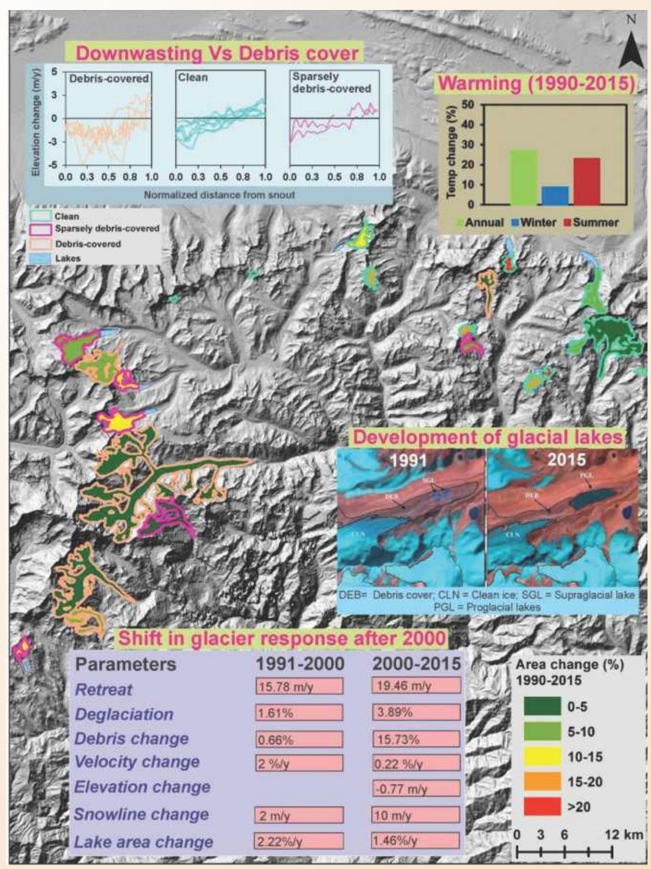

Fig. 74: Multiparametric changes in the selected glaciers of the Sikkim Himalaya during 1991-2015.

which, given the 'summer-accumulation-type' nature of the Sikkim glaciers, seems to be the prime driver of the observed changes.

MoES Sponsored Project

Quaternary Landform Evolution along the Himalayan Frontal Thrust of India: Insight to the patterns of strain release along a Continental Convergent Plate Boundary.

(R.J. Perumal and P. Srivastava)

The NE Himalayan front is constituted of the Brahmaputra Alluvial Plain (BAP) that is densely populated, stretch along the southern edge of the Himalayan Frontal Thrust (HFT), and has the potential loss of life due to likely future occurrence of magnitude 8 or more earthquake, as it already has witnessed many devastating earthquakes. For example, historically documented Sadiya (C.E 1697), and Bhutan (C.E. 1714) earthquakes, and instrumentally recorded Bihar-Nepal (1934) and Assam-Tibet (1950) earthquakes. Thus earthquake geology study is more crucial towards understanding the seismic hazard potential along the eastern Himalayan frontal thrust.

In view of the above context, and under this MoES funded project (5 yrs), ten paleoseismological trenches were excavated across the newly identified fault scarp along the Himalayan Frontal Thrust (HFT) in Sikkim, Arunachal Himalayas and in the frontal Mishmi range to develop the paleoearthquake catalogue. A mega trench was excavated at Himebasti forest village. Along-strike of eastern Himalayan frontal thrust from west to east the trenches are located at Chenga (Post 1604 BCE earthquake event), Panijhora (1255 CE event), Ultapani (Post 74-320 CE event), Himebasti (multiple events at 1697 and 1950 CE), 2 trenches at Niglok (two events at post 324 CE and 1697 CE), Pasighat (1950 CE event) and Kamlang (1950 CE event).

MoES Sponsored Project

Pedological, sedimentological and thermochronological records of climate change during the evolution of Siwalik succession, Punjab re-entrant"

(N. Suresh and Rohtash Kumar -Retd)

Late Cenozoic fluvial stratigraphic records of the HFB- the Siwalik Group, initiated around 13 Ma, were studied to understand the response to allogeneic forcing. The work was carried out on the already measured and paleomagnetic age constrained the Ranital-Kangara section in the Kangra Sub Basin (KSB). The Siwalik succession is well exposed in vast areas in the KSB and is divided into the northern and southern belt by Jawalamukhi Thrust (JMT). All three Sub-groups Lower Siwalik (LS), Middle Siwalik (MS), and Upper Siwalik (US) are exposed in the northern belt, whereas only the MS and US in the southern belt.

Sedimentological studies were carried out along the Ranital-Kangra section. This section is about 3 km thick and comprises the upper part of the LS, MS and US Subgroups, deposited between ~13 and ~3.5 Ma. The LS consisting of interbedded dark grey fine-grained sandstone and purple-brown mudstones. The mudstone exhibits pedogenesis with calcrete, bioturbation, and rootlets. The sandstones display trough-cross stratification and ripple marks and are thin with the ribbon geometry. The MS exhibit marked variation in fluvial architecture and colour of the sandstone. The sandstone represents sheet geometry with low mudstone content. Cycles of the alternating channel and overbank facies were observed. Single to compound paleosol bound overbank sequences are common. The paleosol show grey and green mottling and possess calcareous and ferruginous concretions. Upper Siwalik succession is about 2000m thick and consists of conglomerates with sandstone and rarely mudstone beds. In the lower part of the succession, conglomerate with sandstone and rarely mudstone beds are observed and becoming thickly bedded conglomerates in the up section with increase clast size.

The Middle Siwalik succession mark contrast variation in fluvial architecture and shows two types of vertical stacking pattern; i) clustering of laterally amalgamated thick multistorey channel succession and ii) thick overbank mudstone sandwich within clustered of the large channel network. These floodplain deposits include crevasse-splay, levee, fine- to very fine-grained, buff and grey ribbon sandstone beds, siltstone, and pedogenic mudstones with mottling and trace fossils. The grain size analysis mark dominancy of silt material however, the top section shows a slight increase in clay content. These thick overbank mudstones are deposited around ~10.02 - 9.91 Ma, 9.38 9.26 Ma, and 6.46 - 6.36 Ma and are deposited both under the reported intensified (~10.02 - 9.91 Ma and 6.46 - 6.36 Ma) and normal monsoon (9.38 9.26 Ma). The clay mineral analysis of these flood plain sequences shows a dominance of illite followed by chlorite, smectite, and kaolinite. The topmost flood plain sequence shows a comparatively higher concentration of smectite. The floodplain sequence shows a gradual up section increase in pedogenesis which suggests that channel gradually detached from the floodplain forming an upland floodplain, either due to incision or lateral avulsion.

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Fluvial architecture and composition show marked spatial and temporal variation and have characteristics of large river systems. They are deposited by a confined, gravelly braided stream with well-defined floodplains. The US conglomerate clasts composition includes quartzite (white and pink), limestone, granite gneiss, sandstone (Tertiary), basic volcanic, and others, which suggest these conglomerates are truly polymictic and reveals provenance from the hanging wall of both MBT and MCT. The rapidly increasing topographic gradient in the HFB was probably responsible for contrasting fluvial architecture. Apart from tectonic controls on basin fill, the climate has exerted an influence on the overall distribution of grain size, rate of sediment supply to the basin, and discharge as a result of orographic controlled increase precipitation. This reveals that the variation in the basin-fill stratigraphy can be due to past environmental changes, hinterland tectonics, and climate.

MoES Sponsored Project

Tectono-thermal evolution of the Lohit Batholith along Dibang and Lohit Valleys, India using Fission Track and (U-Th)/He Thermochronology

(Vikas and Koushik Sen)

This project aims to constrain: (a) the timing of shearing event through zircon U-Pb geochronology of leucogranite which intrudes the gneissic host rock; and (b) the thermochronological evolution of the Mishmi Crystalline and Lohit Batholith along Lohit and Dibang valleys using (U-Th)/He thermochronology and Fission Track dating (FT) of zircon and apatite. The first phase of geological fieldwork has been carried out along Lohit valley, Arunachal Pradesh region of NE India. Structural studies have been carried out to map the major shear zones in this region. Bedrock samples have been collected for Geochronology and thermochronology as per the objectives of the project. A geological map of the Lohit valley showing the locations of collected samples for thermochronology has been prepared. A structural data map has been prepared. New zircon (U-Th)/He thermochronological data of five samples from Mishmi Crystalline have been produced. These ages range from 6.94±1.17 Ma to 12.51±2.84 Ma. The ZHe ages obtained from three samples along the Walong Shear Zone range from 7.7±0.23Ma to 10.67±0.22Ma while the two AHe ages are 1.73±0.15Ma and 3.56±0.42Ma respectively in this domain of the eastern Himalaya. Sample preparation for the thermochronological analysis of 17 samples for apatite and 7 samples for zircon have been done to constrain the exhumation pattern of Lohit Batholith exposed along the Lohit Valley. These samples shall be sent for thermal neutron irradiation to obtain the first FT data of this region.

SERB Sponsored Project

Holocene centennial to millennial scale changes in Indian summer monsoon: a multi proxy record from high altitude regions of Uttarakhand Himalaya

(Suman Lata Rawat)

A multi-proxy record (environmental magnetism, TOC %, and grain size) has been generated from a 2.3 m long sedimentary profile from Chamoli Garhwal. The sedimentary profile shows distinct seven charcoal layers at 5-8, 27-34, 39-42, 81-84, 91.5-92, 98.5-99, and 155-159 cm depth intervals. These dark black organic-rich layers have been deposited due to the rapid accumulation of organic matter in warm wet climatic conditions. The chronology is established with 8 radiocarbon AMS ^{14}C dates. The base sample of the profile (at 230 cm depth) yields a radiocarbon age of 9761 ± 110 BP (~11,220 cal yr BP) indicating sediment record covers the entire Indian summer monsoon history of Holocene period. The preliminary results based on the TOC%, environmental magnetism, and grain size analysis indicate strengthened ISM during ~11220-8320 cal yr BP with maximum intensity during 8700-8320 cal yr BP. This strengthens the ISM period corresponds to early Holocene monsoon maxima. Subsequently, from ~8320-5090 cal yr BP weakening of ISM strength is observed with the intermittent warm-wet period between ~7060 and 6580 cal yr BP. From ~5090-2480 cal yr BP stable monsoon conditions were found and enhanced warm-wet conditions after ~2480 cal yr BP up to 1250 cal yr BP. The monsoon strengthens weakened from ~1250 to 520 cal yr BP. Modern improved monsoon conditions in the region were found after ~520 Cal yr BP. The detailed climate interpretation for understanding the mechanism and causes for the change in ISM strength is in progress.

SERB Sponsored Project

Geo-Thermochronological investigation of Lesser Himalayan Crystallines of Garhwal Region, NW-Himalaya: Implication to Extrusion and Duplexing model

(Paramjeet Singh)

In this study, we have taken a transect from Kotdwar-Lansdown-Srinagar-Ukhimath-Gorikund road section and collected total 45 bedrocks samples to carry-out the Fission Track Thermochronology and Geochronological work from the three distinct geological zones, which are separated by two major tectonic boundaries, i.e. the Main Boundary Thrust

(MBT) and Main Central Thrust (MCT)/ Munsiari Thrust (MT) in Garhwal region of NW Himalaya (Fig. 75). The detail of work carryout and sample locations described below:

Sub-Himalaya: Siwalik Group

The Siwalik group is separated by the Main Boundary Thrust (MBT) from the Lesser Himalayan Meta Sedimentary Zone (LSMSZ) in the north. The rocks are very well exposed in the road section of Kotdwar-Duggada Section with coarse-grained sandstone near the Aamshaur village and Kali-Mata Temple represents the Middle Siwalik and Lower Siwalik near to Duggada township and the contact of MBT, which is clearly visible between sandstone and metasedimentary rocks of the Lesser Himalaya. We collected 5 bedrock samples from the lower and middle Siwalik rocks to study the provenance and exhumation history of the Siwalik group.

Lesser Himalayan Meta-sedimentary Zone (LHMSZ)

The Lesser Himalayan rocks are mainly composed of mainly unfossiliferous low grade metamorphic, also known as Lesser Himalayan Meta-Sedimentary

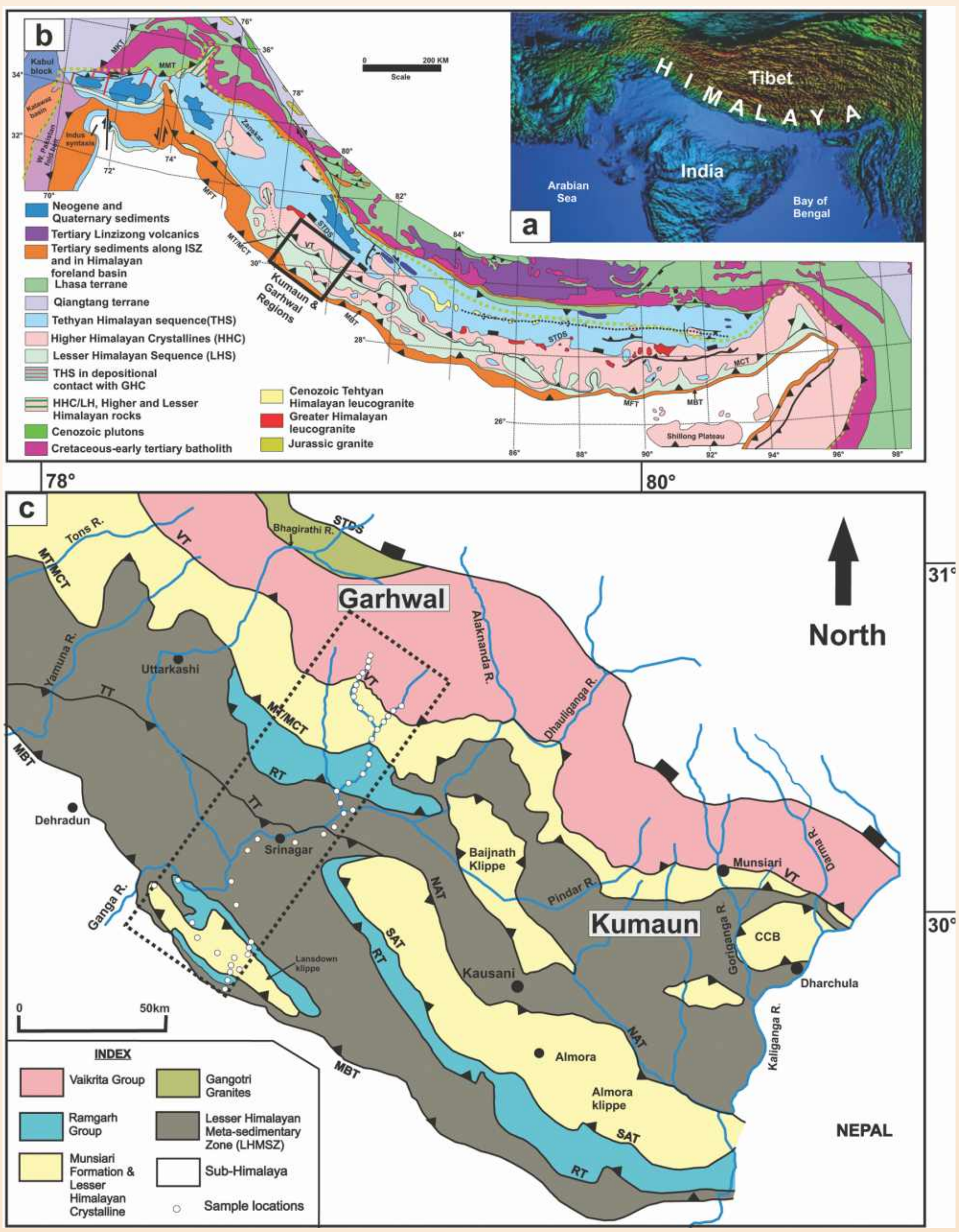

Fig. 75: Topography based on the GTOPO 30 digital elevation model (US Geological Survey) of the Himalaya; (b) Geological map of the Himalayan Mountain Belts (after yin, 2006); and (c) Sample location map and tectonic domains of Kumaun-Garhwal region of NW Himalaya (modified after Singh & Patel, 2014, Valdiya 1980).

(LHMS) Zone rocks and tectonically overlain by low to medium grade crystalline rocks, also known as Lesser Himalayan Crystalline (LHC) Zone (Haim and Gansser, 1939; Gansser, 1964; Valdiya, 1980). For Fission Track Thermochronology, we have collected 15 bedrocks samples from the different tectonic regimes of LHMS. The LHS comprises the (i) Beringag Formation, It is a very thick succession of quartzite and well-known formation, named after Berinag Town. Berinag formation comprises of white, yellowish quartzite. The Berinag and Nagthat formations are separated by Berinag Thrust in the south of MT/MCT. The Beringag formation is very well exposed along the Tilwara-Augustmuni road sections. (ii) Nagthat formation, which is made up of ortho-quartzite, purple phyllite of Precambrian time. The rocks are very well exposed between Tilwara-Rudraprayag-Khirsu road sections. These formations are separated by a south-dipping known as Tons Thrust. (iii) Chandpur formation is made of the pink quartzite, amphibolites, chlorite schist Schitose, calc schist, marble rocks of the northernmost part of outer LHMS. In the north of Lansdown klippe a very sharp contact between Chandpur and Blaini Formation is very well easy traced and rocks are exposed between the traverse Kaudiyala and Bachedikhal. Similarly, dark greywacke, quartzite, shale, arkosic sandstone, calcareous sandstone of Tal formation can be seen between Shivpuri to Kaudiyala.

Lesser Himalayan Crystalline Zone (LHCZ)

Several detached crystalline bodies containing granite bodies overlie the sedimentaries of the Lesser Himalaya. They have been found to occupy the cores of the major synformal structures of the Lesser Himalayan formations, implying that represent erosional remnants of originally large thrust sheets such as the Lansdowne Klippe: The Lansdowne klippe (LK) consists of low-grade metamorphic and granite rocks, polyphased deformed, and characterize various folds, schistosity planes. It is very well exposed along the traverse Duggada-Gumkhal and Duggada-Dwarikhal road section and the Lansdowne town is mainly situated over the granite body which is known as Lansdown granites. The lower part of it is comprised of ganetiferous mica-schist, micaceous quartzite, and augen gneiss. 10 samples for Fission Track Thermochronology and 3 samples for U-Pb have been collected along the above-said transect.

Higher Himalayan Crystalline (HHC)

The traverses from Kanda (Ukhimath) to Gaurikund (Kedarnath) along the Madakini valley have been taken in this study and represent the Higher Himalayan Crystalline zone. The detailed geological studies show that the HHC is made up of low-grade metamorphic rocks of the Munsiari Formation and the higher-grade metamorphic of the Vaikrita Group. The Munsiari Thrust is considered as MCT in this study that separates the LHMS zone from the medium to high-grade metamorphic rocks of the HHC. The Vaikrita Thrust is considered as another thrust within the HHC that separates the higher-grade Vaikrita Group from the low-grade metamorphics of Munsiari Formation. During this field, we have generated the structural dip-strike, lineation, foliation data, and various structural features such as major bounding thrust, Shear sense indicator, the dominant litho-tectonic unit which are essential to reconstruct the tectonic history of the area.

Status of Geo-Thermochronological work

(i) Fission Track Thermochronology: 45 samples have been irradiated from FRM II (Germany) in January 2020 and waiting to receive back from FRM II.

(ii) U-Pb (zircon) Geochronology: Total 8 samples prepared and ready for CL image and Geochemistry (using XRF, ICPMS) work of 30 samples have been completed.

SERB Sponsored Project

Hydrological cycle analysis in valleys of Pindari-Kafni glaciers, Kumaun Himalaya

(Pankaj Chauhan)

A research project have been implementing in the capacity of a Principle Investigator (PI) titled "Hydrological cycle analysis in valleys of Pindari-Kafni glaciers,Kumaun Himalaya" sponsored by SERB, DST, Government of India (DST No: EEQ/2016/000292). The cost of the project is Rs. 20, 07, 7000/- (Twenty lakh seven thousand only). The project involves the applications of remote sensing as well as field based real time monitoring of meteorological data and glacial stream discharge measurement. The objectives involves are: To compute the evapotranspiration at daily to interannual timescale. Analysis and quantification of discharge from Pindari and Kafni Glaciers. To calculate the seasonal and interannual water balance. Delineation and characterization of snow and ice melt, rain from Pindari, Kafni glaciers using stable isotopes and separation of hydrograph through isotopic methods. Estimation of suspended sediment concentration and suspended sediment load.

The Pindari and Kafni glaciers lies in the Pindar valley, Alaknanda basin, Kumaun Himalaya in the central Himalaya and located in the Bagehswar district of Uttarakhand state (Fig 76). The total length of Pindari

Glacier is about ~5.9 km and covered an area approximately 9.6 km^2 and the Kafni glacier has occupied about ~ 3.3km^2 with 4.21km of the glacier length. The valley lies between latitudes 30˚ 12′ 15″ - 30˚ 19′ 10″ N and longitudes 79˚ 59′ 00″- 80˚ 01′ 55″ E. The whole Pindar basin occupied about ~173 km^2, glacierized area about ~ 9.2 km^2, elevation range ~2570 to 6183m) located in the central Himalayan region.

Handheld AT-RH meter and Open PAN evaporimeter and rainfall event logger have been procured and installed at Dwali site (Fig. 77a-c). A meteorological observatory/ automatics weather station (AWS) containing sensors for monitoring vital met-parameters, viz., air temperature, relative humidity, wind speed, wind direction, rain gauge and soil temperature have also been installed at kafni glacier zero point during 2018-19 (Fig 77d). Another semiautomatic hydrological suspended solid analyzer has also been procured to estimate the sediment budget of the glacier valley (Fig 78-f).

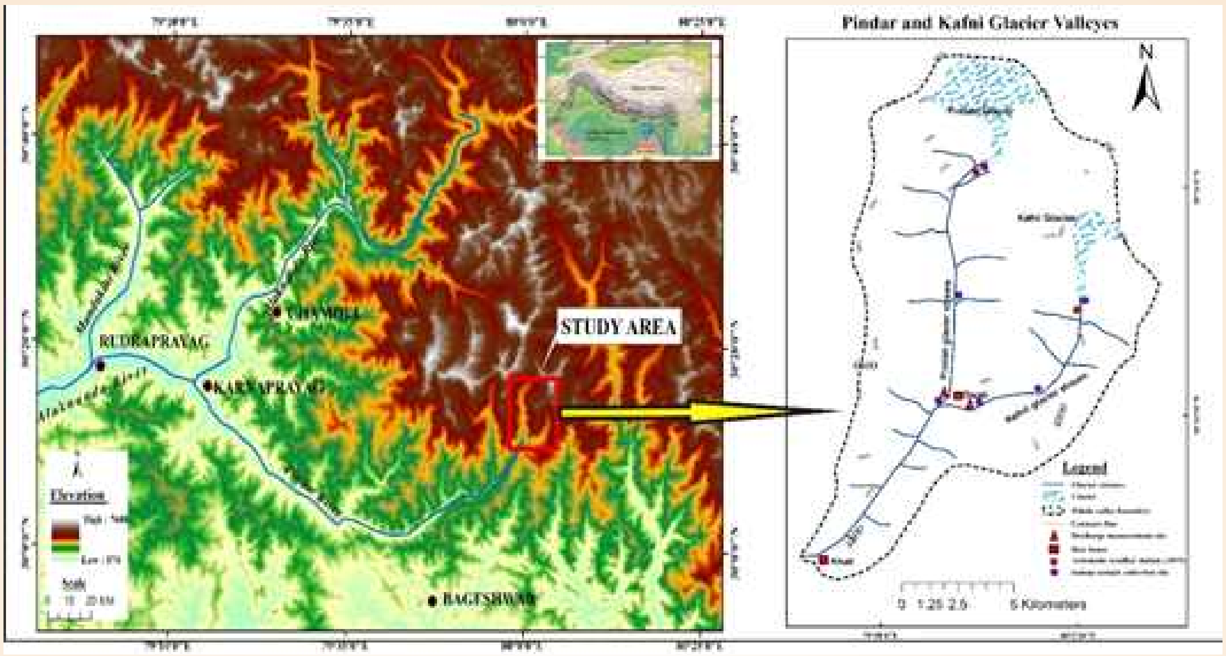

Fig. 76: Map of the study area.

Fig. 77: (a-c) AT-RH meter, rain gauge and Evaporimeter installed at Dwali station. (d) meteorological Observatory/ AWS established at Kafni glacier zero point.

Fig. 78: (a-b) show construction of discharge site, measurement of stage and cross sectional area of the stream, (c-d) display collection of samples for isotopic analysis, (e) sediment filtration process to quantify the SSC and SSL and (f) testing semiautomatic suspended solid analyzer.

Field visit also carried out for data collection. During the field visit, two discharge sites (20m long and 20m wide) have been constructed, one at Pindari stream which lies at latitudes 30^0 10' 41" N and longitudes 79^0 59' 39" E at an altitude of 2631m above sea level (asl) and second at Kafni stream, at latitudes 30^0 70' 36" N and longitudes 79^0 59' 40" E at an altitude of 2590 m asl. Both sites are located near the Dwali station and are constructed before the confluence of Pindari and Kafni streams (Fig. 76).

Meteorological and hydrological analysis

Three years meteorological data of AT-RH (Air temperature & relative humidity), and Precipitation from Dwali station has been collected and analysed. Minimum maximum, average details of meterological data have been presented in tabulated from**.** Three years (2017-2019) runoff data of the glacier melt from each valley have also been collected and investigated and presented in tabulated form. Three years SSC, SSL, sediment yield and erosion rate have been quantify and presented in table 2. It is observed that maximum percentage of discharge, SSC (suspended sediment concentration) and SSL (suspended sediment load)to be estimated in the months of July and August in three hydrological years (2017-19). Behaviour and pattern of the discharge shown in (Figs 79, 80). Sediment yield from Pindari and Kafni glacier estimated to be 1031.01 t/km^2/yr and 988.54 t/km^2/yr respectively. Erosion from the Pindari and Kafni glacier valleys were quantified 0.38mm/ye and 0.37mm/yr respectively, these rate are lower than the erosion rate of other parts of the glacier valleys and average rate of the Himalaya (Table 1). It has also observed that discharge has good correlation with SSC and SSL (Fig. 81).

An assessment of discharge, SSC, SSL, sediment yield and erosion rate has been undertaken for the two adjacent glacier glacier streams Pindari glacier stream (PGS) and Kafni glacier stream (KGS) at the confluence of the both streams. The valley is the part of Kumaun central Himalayan region. Data were collected from different ablation seasons (2017-2019) with an uncertainty of ± 5%. Mean monthly SSC for the May, June, July, August, September and October during the study period was 1135, 2146, 7886, 7913, 3395, and 12146 mg/L from the PGS and 1043, 2043, 7340, 7379, 2893, and 809 mg/L from the KGS in the same ablation months. The entire ablation season mean monthly SSC was computed to be 3948 ±1293 (±SE) mg/L from PGS and 3585 ±1232 (±SE) mg/L from KGS. The maximum SSC was observed in the month of July and August accounting above ~67% from the both glacier streams.

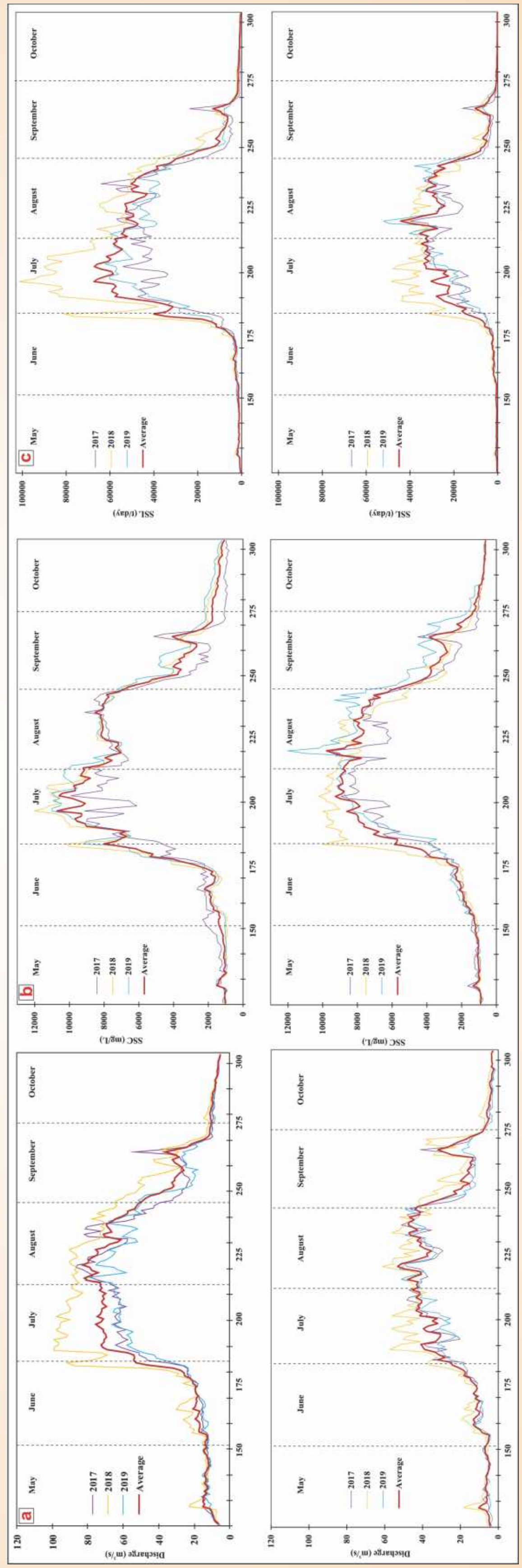

Fig. 79: (a,b,c upper panel), Pindari daily mean discharge, suspended sediment concentration (SSC) and suspended sediment load (SSL) respectively, and (a,b,c lower panel) from Kafni glacier stream from 2017-2019.

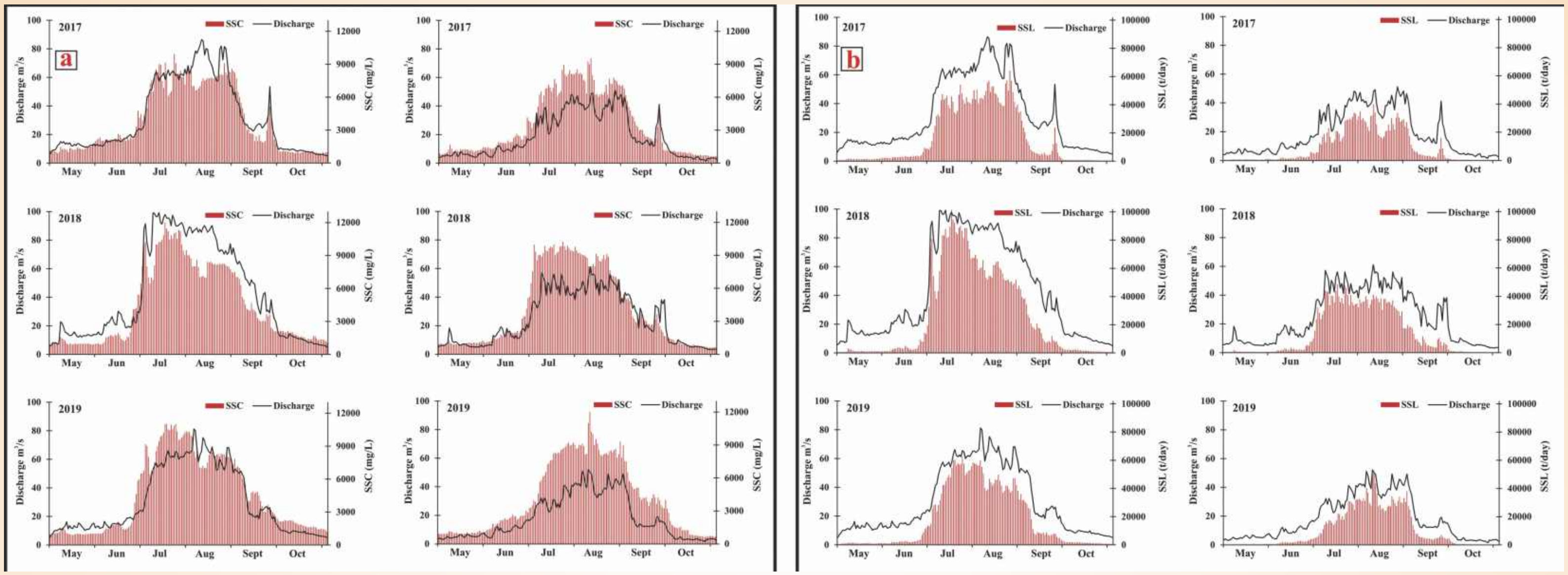

Fig. 80: (a, Monthly mean discharge, suspended sediment concentration (SSC) and suspended sediment load (SSL) behaviour of the Pindari glacier stream (left panel) and (b)Kafni glacier stream (right panel) from 2017-2019 hydrological years.

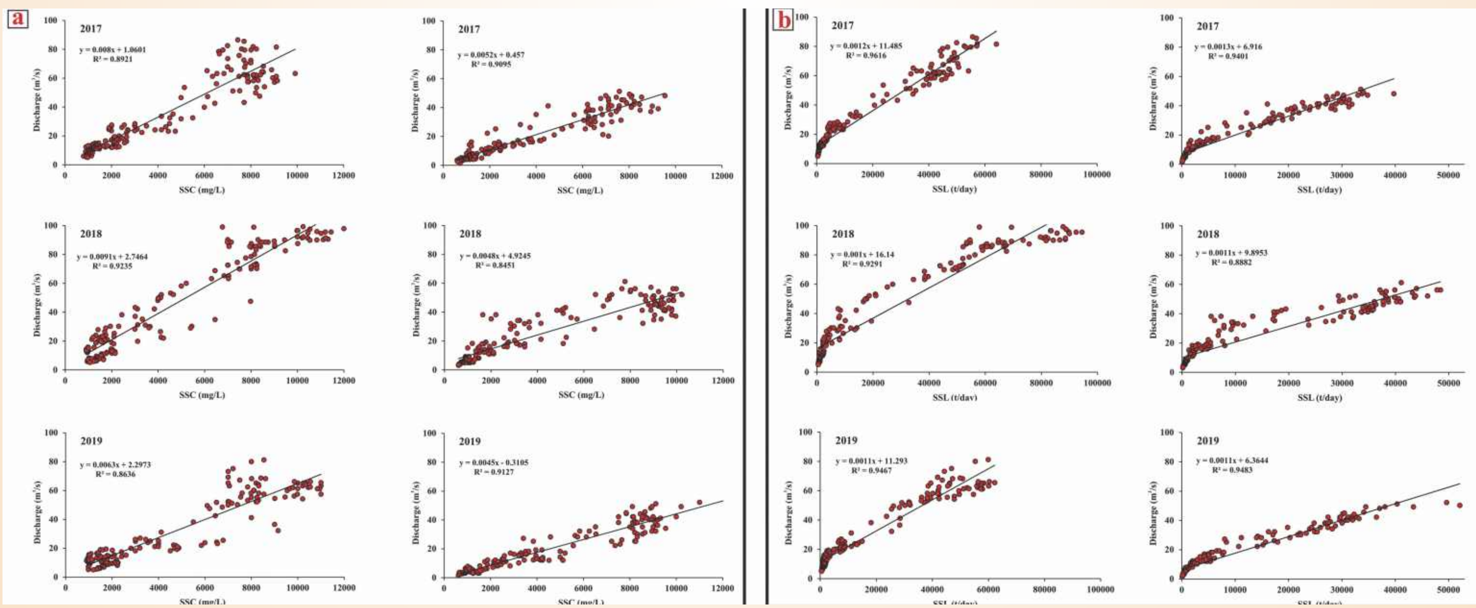

Fig. 81: In (a, left panel) year wise discharge, SSC and SSL relationship of the Pindari glacier stream, and Kafni glacier stream (b, right panel) from 2017-2019 hydrological years.

Table 2: Computed sediment yield and erosion rate in studied period (2017-2019) from Kafni and Pindari glacier streams, and comparison with other study in tthe Himalayan region.

Glacier/River	Region	Basin area (km^2)	Sediment yield ($t/km^2/y$)	Erosi on rate	Observation period	Source
Pindari Kafni	Alaknanda River (upper Ganga basin)/ central Himalaya	111.0 62.0	1031.01 988.54	0.38 0.37	(May-Oct 2017-2019)	Present study
Chorabari	Mandakini/central Himalaya	15.4	4064.3	1.5	(June-Sept., 2009-2012)	Kumar et al. (2016)
Dokriani	Bhagirathi/central Himalaya	16.1	2800	1.0	(June-Sept.,	Singh et al. (2013)
Gangotri	Bhagirathi/central Himalaya	556.0	4834	1.8	(May-Oct., 2000-2003)	Haritashya et al. (2006)
Tons river basin	Chandra/western Himalaya	34.7	3001	1.1	(May-Oct., 2011-2014)	Singh et al. (2018)
Tons river basin	Garhwal lesser Himalaya	41.2	894	0.33	(Jan.-Dec. 2008-2011)	Chauhan et al. (2017)
Punatsanchh	Bhutan/eastern Himalaya	6271	377	0.28	1992-2008	Sonam Choden (2009)

SSL has found the same pattern from the studied glacier and accounting above ~85% of the total. Comparison between the adjacent valleys PGS has generated slightly high discharge, SSC and SSL. In terms of sediment yield and erosion rate, PGS computed to be 1031 ±180.77 (±SE) t/km2/yr and 0.38 ±0.07 (±SE) mm/ yr, whereas KGS has generated 988.54 ±166.01 (±SE) t/km2/yr and 0.37 ±0.06 (±SE) mm/yr sediment yield and erosion rate respectively. Sediment yield and erosion rate from PGS is slightly high from the KGS. SSC, SSL, temperature and precipitation has observed strong relationship ($R^2 = 0.8$) and above with discharge especially in the monsoon months. Average study period (2017-2019) (Cv) in SSL was estimated to be 1.18 from PGS and 1.22 from KGS. These values are less than that of Dokriani, Gangotri, Chorabari and Chota Shigri glaciers, but a variability in SSL from the present study quantify to compare from the Alpine glaciers is higher. Whole Pindari basin erosion rate was computed to be 0.4 mm/yr, which is lower the average erosion rate of the Himalayan. Whereas the present erosion rate value is higher than studies carried out in the low altitude area i.e. Tons watershed and Arun river watersheds in lesser Himalaya and Punatsanchhu watershed in Bhutan.

Evapotranspiration quantification: Initially open pan evaporimeter was installed at Dwali station and same machine was also installed at Pindari glacier zero point by Centre for Glaciology (WIHG). Since last two years we rigorously trying to measure the reading on daily basis from this open pan evaporation machine, but we are unable to find out the significant values for analysis. Results we found from this machine are very inaccurate and insignificant, which can't be practice for the future research purpose. Findings behind this open-pan machine that, an open pan is not suitable instrument to measure the evaporation in the study area, but sophisticated automatics instrument would be valuable to find out the accurate results for further investigation. To achieve the objectives we will use the meteorological and modelled data to estimate the evapotranspiration and to also compute the hydrological cycle of valley.

Isotopes data analysis

Approximately 400 samples of surface, ground and snow melt water for isotopes were collected in Kafni and Pindar valley form different locations and altitude on fortnight basis. 300 samples have been analysed and rest of 100 samples are in queue and soon it will be in from of the research article.

SERB - NPDF Scheme

Stable carbon and oxygen isotopic studies of the Paleocene-Eocene sequences of Kachchh, western India and their implications on the paleoenvironment of the western Indian shelf

(Vineet Kumar Srivastava)

The financial year 2019-20 was dedicated to petrographic and geochemical investigation of the Eocene shales and carbonates of Kachchh Basin, western India. Paleoenvironmental conditions prevailed during occurrence of early Eocene Naredi Formation, middle Eocene (Lutetian) Harudi Formation and late middle Eocene (Bartonian) Fulra Limestone Formation (Fig. 82) are reconstructed based on a comprehensive facies analysis and their stacking

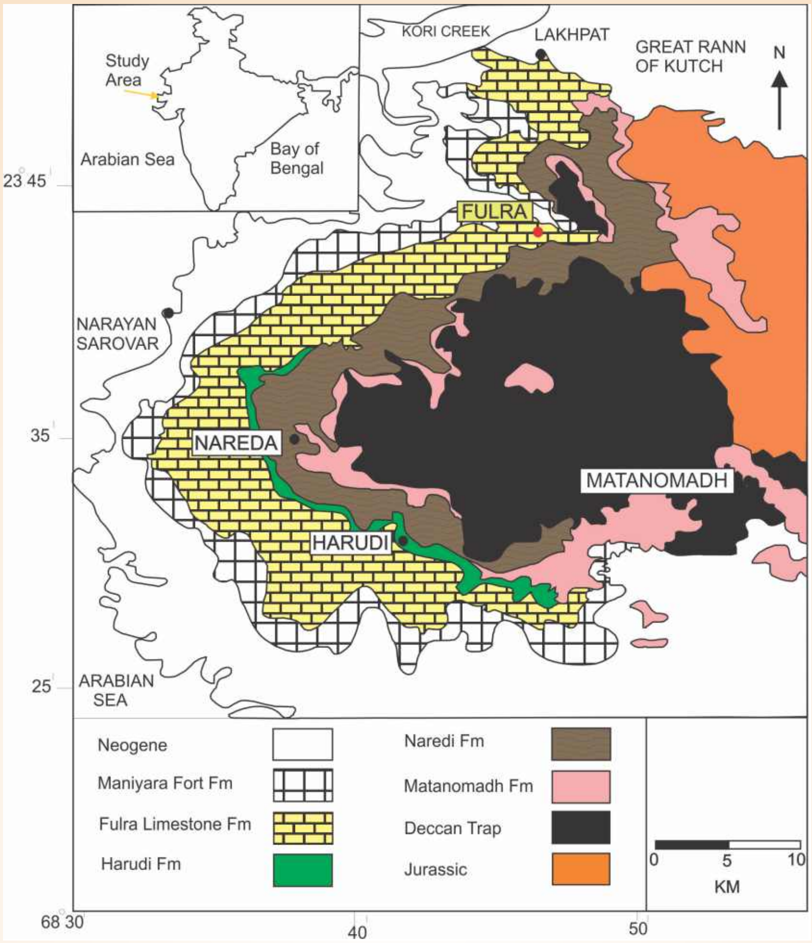

Fig. 82: Geological map of the Paleogene succession of Kachchh Basin, western India (after Biswas, 1992).

pattern supported with mineralogy and geochemistry. It is noticed that even during the phase of 2nd order marine transgression and carbonate platform development in Eocene, clastic influx was operated mainly in the form of suspended sediments due to excessive weathering on adjacent continent in warm and humid climatic conditions that lead to the deposition of shales, gypsiferous mudstones and wackestone facies having appreciable terrigenous influx in between the packstone and grainstone facies of completely carbonate origin. Presence of kaolinite as one of the major constituents during bulk rock mineralogy of shales, mudstones and its appreciable proportion among the micritic component of various limestone facies is indicative of warm and humid climatic condition prevailed on adjacent continent and derivation of clays from extensive weathering of Deccan basalt. Based on shale-carbonate wackestone packstone-reefal-coralline facies association along with the presence of key minerals such as glauconite, pyrite, siderite and anhydrite and their genetic link to characteristic depositional milieu, fluctuating depositional environments from lagoonal-barrier ridge to lagoonal-tidal flat are proposed for the Naredi Formation. Similarly, the depositional environments of the Harudi Formation varied from lagoonal to supratidal conditions in the lower part followed by middle shelf-inner shelf-tidal flat conditions in the upper part based on mudstone-shale-limestone-evaporite facies association and the mineralogical constituents of kaolinite, gypsum, goethite, glauconite, calcite and smectite.

Moreover, facies association in the Fulra limestone shows two cycles of shallowing upward carbonate sequence that would have developed on the middle to inner ramp and lagoonal depositional environments. The depletion of LREE and slight enrichment of HREE in the Eocene limestones of Kachchh Basin suggests seawater-like REE pattern. The negative Ce anomaly further suggests that the REE were introduced directly from the seawater under oxic conditions, whereas positive Eu anomaly suggests that some siliciclastic sediments were incorporated in these limestones. The similar paleoenvironmental and varied hydrological conditions are well reflected in the stable C and O isotopic values with slightly negative $\delta^{18}O$ and $\delta^{13}C$ values except for dolostones which indicate fairly positive $\delta^{18}O$ and extremely negative $\delta^{13}C$ values that indicate different hydrological regime and degree of diagenesis. Furthermore, origin and plausible processes responsible for the occurrence of 16 m thick late middle Eocene dolostone succession western Kachchh were discussed in detail based on microfacies, petrography and stable C and O isotope geochemistry. The slightly negative to positive $\delta^{18}O$ values (-0.99 to 1.70‰) indicates semi-closed lagoonal environment where dolomitization was mediated through combined effect of evaporative pumping of seawater alongwith freshwater influx. While, the highly negative ^{13}C values (-25.98 to -38.83 ‰) are attributed to the combined effects of anaerobic decomposition of organic matter by sulphate reducing bacteria and oxidation of biogenic methanes. The oxygen isotope based paleotemperature measurement ranges between 18- 32 °C and infers the dolostone succession formed in a low temperature condition that was feasible in the coastal or shallow marine environment with partial mixing of meteoric water (Fig. 83).

SERB Sponsored Project

Three Dimensional Attenuation tomography from strong ground motion data for Garhwal region, India

(Parveen Kumar)

In this work, attenuation characteristics of P-wave and S-wave are explored for the Garhwal and Kumaon Himalaya. The strong motion data of 105 local earthquakes recorded in the Garhwal and Kumaon region are considered for the analysis. For the Kumaon region, 221 waveform records recorded at eleven stations are used to estimate $Q_\alpha(f)$ and $Q_\beta(f)$ at each recording station. Similarly, for the Garhwal region, 114 strong motion records recorded at five stations are utilized to estimate Q_α and Q_β as shown in Figure 84. In this work, the attenuation properties of Garhwal and Kumaon regions are correlated with each other to evaluate seismic hazard potential zone. For the estimation of the quality factor, almost similar data set is considered for both the regions consisting (1) epicentral distance ≤ 80 km and (2) depth range 3- 20 km and 5-21 km for Garhwal and Kumaon regions, respectively. Apart from similar data set, the same methodology i.e. coda normalization method is implemented for both regions to compare its attenuation properties. To have better azimuthal coverage maximum number of available events is considered at a single station. The consideration of a large number of earthquakes at each station is also useful to get a better assessment of the results. The site-specific $Q_\alpha(f)$ and $Q_\beta(f)$ values are estimated at each recording station. Moreover, the average $Q_\alpha(f)$ value of two horizontal components provides the final $Q_\beta(f)$ relationship at each recording site. The regional relationship obtained by using site-specific quality factor relations are $Q_\alpha(f)=(55\pm3)f^{(0.90\pm0.06)}$, $Q_\beta(f)=(74\pm5)f^{(0.87\pm0.08)}$ for the Garhwal region and $Q_\alpha(f)=(34\pm1)f^{(0.94\pm0.03)}$, $Q_\beta(f)=(58\pm2)f^{(0.90\pm0.02)}$ for Kumaon region, which clearly suggests the existence of spatial

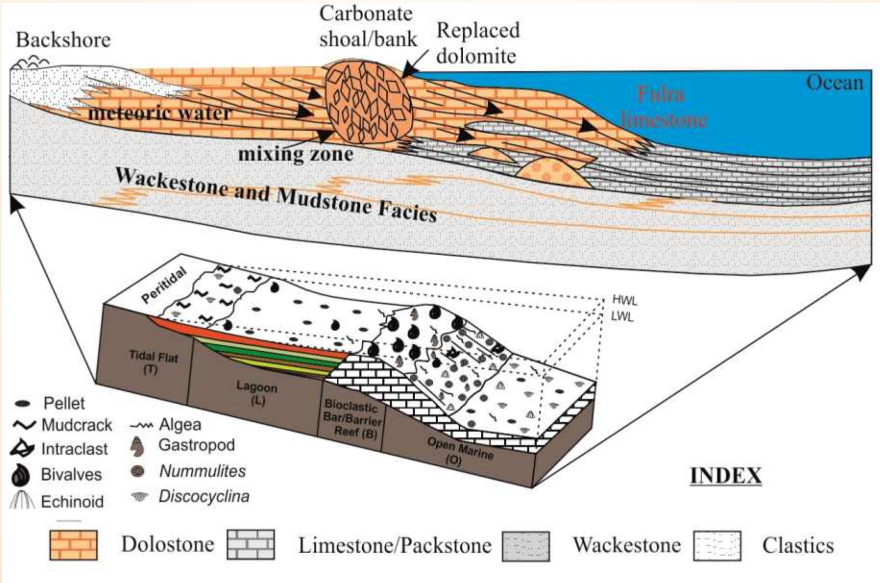

Fig. 83: Cartoon exhibiting the depositional realm of the middle Eocene carbonates of Kachchh Basin, western India (modified after Flügel, 2010).

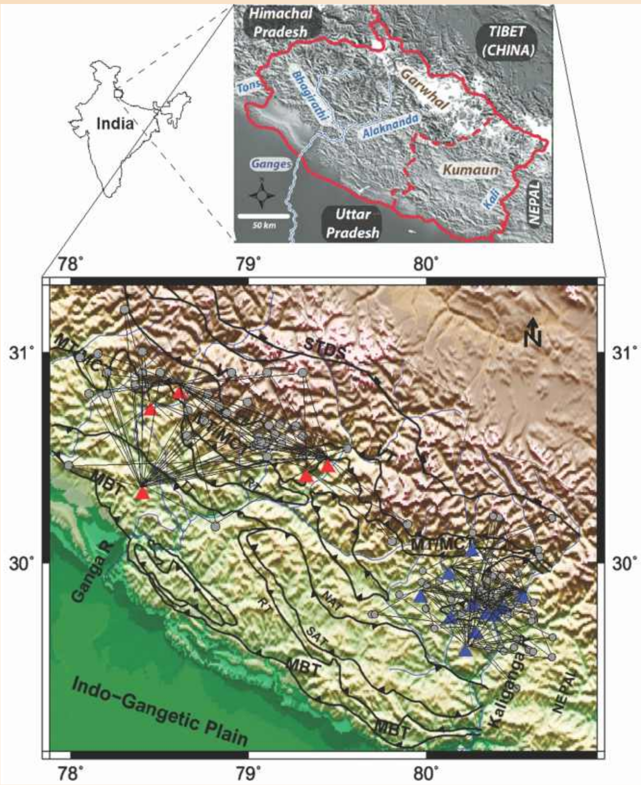

Fig. 84: The Projection of ray path from the epicenter of events to recording stations. The symbol circle and triangle show the location of epicenter and recording stations, respectively. The figure is modified after Célérier et al., 2009a, and tectonic are considered after Valdiya, 1980.

variation of attenuation properties in these two regions. The low value of Q_o (< 200) and the high value of n (> 0.8) obtained for both Garhwal and Kumaon regions demarcated these regions as highly heterogeneous and tectonically active.

The $Q_\alpha(f)$ and $Q_\beta(f)$ relationships are computed individually at each recording station for both the Garhwal and Kumaon regions. The obtained 'Q_o' values for $Q_\alpha(f)$ relation varies from 53 to 58 and 26 to 43 at the different station for the Garhwal and Kumaon regions, respectively; whereas 'Q_o' values for $Q_\beta(f)$ relation varies from 86 to 93 and 44 to 76 at the different station for the Garhwal and Kumaon regions, respectively. Similarly, the values of 'n' for $Q_\beta(f)$ relation varies from 0.89 to 0.93 and 0.89 to 0.98 at the different station for the Garhwal and Kumaon regions, respectively; whereas 'n' values for Q(f) relation varies from 0.84 to 0.88 and 0.85 to 0.94 at the different station for the Garhwal and Kumaon regions, respectively. It is observed that the Kumaon region has low 'Q_o' and high 'n' as compare to the Garhwal region, which reveals that the Kumaon region is highly heterogeneous and more tectonically active. The comparison of obtained regional relations of $Q_\alpha(f)$ and $Q_\beta(f)$ for both the regions clearly disclose that the Kumaon region has a high rate of attenuation as compare to the Garhwal region as shown in figure 85.

The probable reasons for the distinct properties of attenuation for Garhwal and Kumaon regions are (1) both regions have a different type of rocks/geology and (2) presence of fluid. It is found that the geology of both regions is almost similar, both Garhwal and Kumaon regions have common formations like Munsiari, Deoban, Rautgara and Berinag formation consist metasedimentary rocks i.e. quartzities, dolomite, slate, gneiss, and schist. Hence, it is difficult to say that geology is responsible for the distinct attenuation characteristics of Garhwal and Kumaon regions. Therefore the other factor i.e. presence of fluid or partially saturated rocks may be the controlling factor for the diverse behavior of attenuation properties of these two regions.

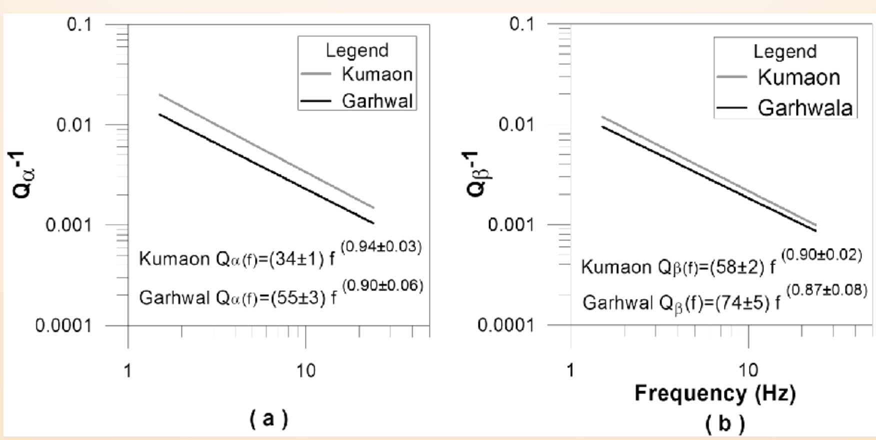

Fig. 85: The comparison of obtained regional relation for (a) P-wave and (b) S-wave for Garhwal and Kumaon region.

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WoS-A Scheme DST

Palaeobiology and Palaeoenvironmental Reconstruction of the Eastern Krol Belt, Himachal Pradesh

(Rajita Shukla)

Kamlidhar, Nigalidhar, and Korgai synclines, a part of the Krol Belt of Lesser Himalaya in Himachal Pradesh, form the study area for the project. A complete sequence of all lithological units of the Krol Belt (i.e. Blaini, Infrakrol, Krol Sandstone, Krol, and Tal sequences) is present within these three synclines, which represent the Precambrian-Cambrian transition. The focus of the project is the study of palaeobiological entities from these synclines to develop a biostratigraphic correlation scheme and understand the evolutionary changes.

A study of chert thin sections has been carried out on samples collected during the earlier field works. Cyanobacteria and algal forms are predominant while the characteristic acritarch population is sparse. Few species of *Siphonophycus*, a filamentous genus are the most prominent biotic entities observed so far. This genus is the most common constituent of the Neoproterozoic microfossil assemblage and is indicative of low energy, intertidal environment of deposition. A septate filamentous form belonging to Genus *Oscillatoriopsis* is also observed. Some scattered coccoidal forms are observed. The morphology of these coccoids is very variable and may be due to taphonomic imprints. A few acanthomorphic acritarchs have been observed which are smaller in size and thus different from the reported assemblage of this time plane. *Cavaspina* and *Wiesiella* are the acritarch genera identified so far. These forms are typical of the Ediacaran Period and will be helpful in biostratigraphic correlation.

Trace fossils have been recorded from the phyllitic silty lithology in Nigalidhar Syncline near Koti Dhaman. They have been identified at a generic level. *Palaeophycus* is the dominant genus with *Planolites* following a close second. *Skolithos, Chondrites, Treptichnus,* and *Rusophycus* are subordinate traces. These traces indicate a pre-trilobite assemblage.

DST-INSPIRE Faculty program

Lake sediments - a natural laboratory to study the past climate variability

(Praveen Kumar Mishra)

This study is focusing on the lake sediments from the Indian sub-continent. Based on the multiproxy approach (e.g., elemental and isotope geochemistry, hydrochemistry and biological proxies), the study aims to (i) understand the present sedimentation pattern in lake basins by surface sediment sampling, sinking particles, and water column investigations; (ii) increase the spatial coverage of the palaeo-data for obtaining a better understanding of the past climate variability, and (iii) understand the monsoonal relationship with different teleconnections (e.g. ENSO, IOD, Active-break cycle). In the previous year, we have achieved our three objectives: (a) understand the factors (such as fluvial, tidal or anthropogenic activities) affecting the modern processes in Ashtamudi estuarine sequence (Fig. 86); (b) reconstruction of past climate variability in terms of south-west and north-east monsoon based on the paleoclimate study from Ennamangalam Lake in southern India (Fig. 86); and (c) a review work focusing on the Holocene climate variability and the cultural dynamics in the Indian subcontinent.

Last year, we have completed the field expedition in *Renuka Lake*, to understand the modern sedimentation processes and the influence of human activity in the lake basin (Fig. 86).

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Landslide Hazard Assessment in NE India along the Gangtok-Tsomgo/Changu Lake and Gangtok/ Chungthang-Lachen Corridors

(Vikram Gupta)

This is a joint Indo-Norwegian project involving Geological Survey of Norway, Trondheim (Norway), Norwegian Geotechnical Institute, Oslo (Norway), Indian Institute of Technology, Kharagpur (India) and Wadia Institute of Himalayan Geology, Dehradun (India).

During the reporting year, analysis of the inventory of the prepared active landslides was carried out. More emphasis was on the spatial distribution of landslides along the Teesta river in a stretch of ~ 95 km between Lachen and Ranggpo. The entire area has been divided into three zones based on various geomorphic indices, like steepness index (KSn), valley floor width to valley height (Vf) ratio, stream length (SL) gradient index, and swath profile. These zones are briefly discussed hereunder:-

Zone I:- Lachen to Chungthang

Zone I, extending from Lachen to Chungthang in the Higher Himalaya is 22 km long along the tributary Lachen Chhu. This zone exhibits 14 rock avalanches and 12 debris slides, thus there is an average of ~1.18

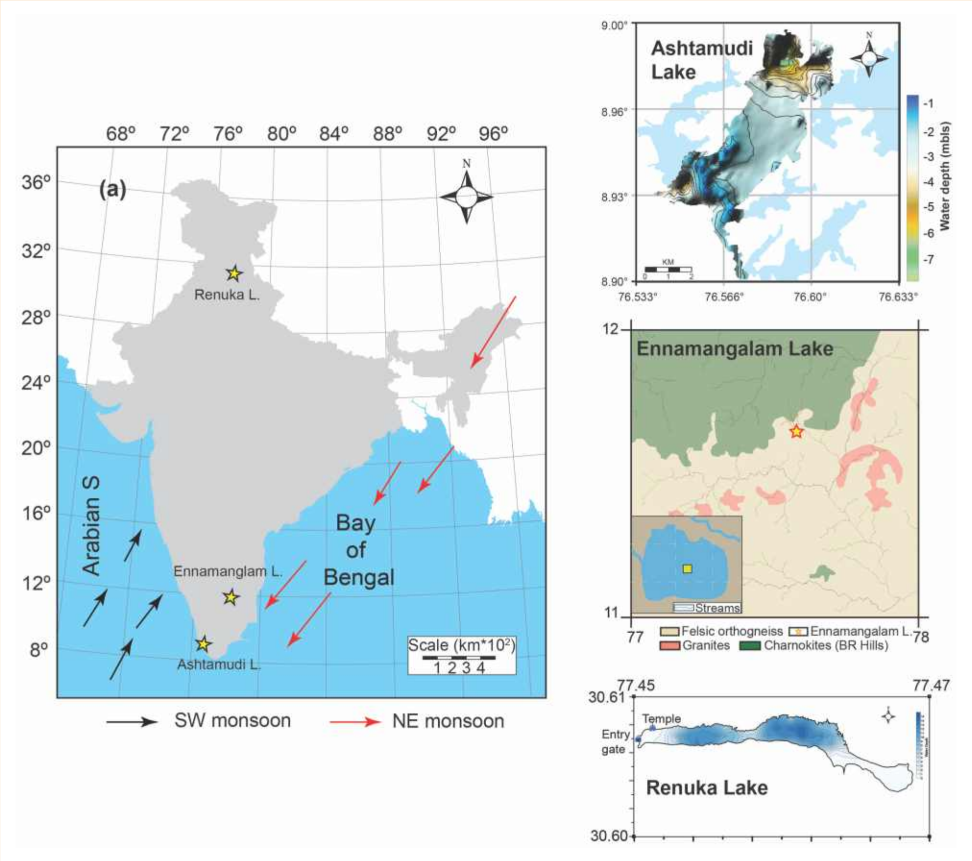


Fig. 86: Location of the lakes, discussed in the text.

landslides per km along the river Lachen Chhu. The channel gradient in this zone is ~ 50 m/km. This zone lies in the Higher Himalaya and mainly consists of the Higher Himalayan Crystalline (HHC) rocks mainly constituting hard gneisses. The slopes in this zone are mainly steep and are covered with thick vegetation. Three knick points observed in this zone indicate geomorphometric anomalies, with higher KSn and lower Vf values. In general, this zone is characterized by higher KSn, lower Vf, moderately higher SL index, all these support higher erosional rates, and higher tectonic activities and is also evidenced by the various geomorphic indicators like deep narrow gorges, high topographic relief, and rock avalanches. Similar kinds of observations have also been observed in the north of the MCT in the higher Himalaya from various other parts of the northwestern Himalaya. Further, it may also be noted that this zone lies behind the orographic barrier, thus lower average annual rainfall is expected in this zone

Zone II:- Chungthang to Rangrang

Zone II extending from Chungthang to Rang Rang is ~ 23 km long along the Teesta river. This zone exhibits 27 landslides, of which 17 are rock avalanches and 10 are debris slides. Thus there is an average of ~ 1.17 landslides per km along the river Teesta. The channel gradient in this zone is 37 m/km. The zone lies to the immediate north of the MCT, thus a pronounced increase in topography north of this zone has been observed. Like Zone I, this zone is also occupied by gneisses and with granitic gneisses. In general, the slopes in this zone are steeper with narrow valleys. The SL index is highest indicating that higher erosional potential in this zone. Overall, the values of KSn is higher in a zone I and zone II, however, in the vicinity of the two knick points, marked by the major thrusts, these are observed to be the highest. Since this zone lies in the vicinity of the MCT and the immediate front of the orographic barrier, this zone is characterized by a higher amount of rainfall *cf* rainfall in zone I. Therefore, some of the major landslides like Rangrang landslide and Mantan landslide that are posing threat to the inhabitants are located in this zone. Besides, there are many small scale landslides in this zone that cause frequent damages particularly along the North Sikkim highway and to the habitation of the Mangan township. Therefore the landslides in this zone owe their origin to both the tectonic and rainfall.

Zone III:- Rangrang to Rangpo

Zone III located between Rangrang and Rangpo is ~ 50 km in length along the Teesta river and the channel gradient in this zone is ~ 12 m/km. This region lies in the Lesser Himalaya which is mainly comprised of metasedimentary rocks like phyllites, schist, and quartzites. This zone is occupied with 16 widely spaced debris slides. It is interesting to note that this zone is devoid of any rock avalanche. This zone is characterized by low KSn, low SL, and comparatively higher Vf values indicating that this zone experiences relatively lesser tectonic activity. In general, the valley slopes in this zones are relatively gentler *cf* the slopes in the higher Himalaya, as the slopes in this zone might have attained angle of repose. Further because of the gentler slopes, the erosion potential in this zone is relatively slower. Therefore most of the landslides in this zone are climatic controlled and are rain-triggered.

DST Sponsored Project

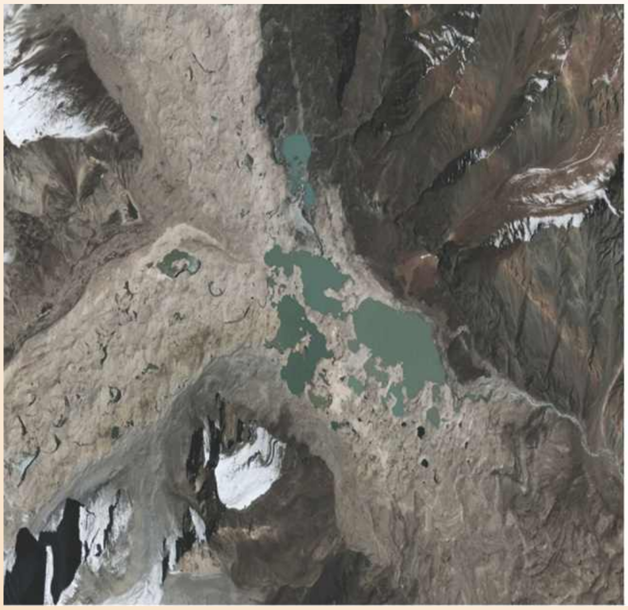
Status of geo- resources and impact assessment of geological (exogenic) processes in NW Himalayan Ecosystem under National Mission of Sustaining Himalayan Eco-system (NMSHE)

(WIHG Director, Rajesh Sharma, D.P. Dobhal and Vikram Gupta)

This National Mission project on Sustaining Himalayan Eco-system mainly pertains to establishing database and knowledge based information system about the geological resources (Quaternary deposits, groundwater, springs including geothermal springs, mineral resources and snow cover), and the exogenic geological processes (mass - movements including GLOF) along the major valleys, to facilitate policy decision on the sustainable development of Himalayan Ecosystem. In this connection, following database have been collated from the previous studies carried out by various researchers, and added with new information generated.

Glacial Lakes- Basudhra Lake (East Kamet Glacier) between 2001 and 2017

The 'Basudhara' Lake (Fig. 87) is one of the lakes in the region, which is expanding in area since last few years. This is an ice dammed lake, located in the East Kamet glacier (4690m asl) in Niti valley, Dauliganga river basin in the Chamoli district of Uttarakhand. The lake is formed over the glacier surface near the termini of East Kamet glacier (16 Km, extend between elevation 4449m and 6545m). The lower ablation area is thickly debris coved. An attempt has been made to evaluate the present status and its potential to turn into GLOF in near future. The glacier surface area was mapped through Landsat images for the year 2001, 2013 and 2017 and changes in glacier surface area were outlined each time period and compared to acquire net change in area of the glacier lake. The preliminary study shows that the area of lake is continuously increasing as it was 33.61 ha in 2001, 48.18 ha in 2013 and 60.67 ha is estimated in 2017. The estimated total increase is ~ 27.06 ha ± 10ha during last 16 years.



S. N.	Parameters	The Basudhra Lake (East Kamet Glacier)
1.	Location/Co-ordinate	10 km upstream of Niti village in the East Kamet Glacier, Chamoli district, 30^{0}53′ 06″: 79^0 46′ 17″,
2.	Catchment Area(km2)	~127 km^2
3.	Surface area (ha)	60.67ha
4.	Length & width (m)	790 m *445 /85m
5.	Elevation	4449 m asl
6.	Type	Ice dammed
7	Out flow	Proper out- let
8.	Source	Snow, ice melt,

Fig. 87: Location of Basudhara Lake over the East Kamet glacier with salient features.

Springs

In Uttarakhand, more than 90% of the rural population depends on natural springs which are often not easily accessible. Dependence on groundwater through tube-wells and hand-pumps in the intermountain, adjacent piedmont, and in plain areas is an economical solution for the perennial supply of drinking water. To understand the condition of groundwater reservoirs, we have compiled the historical and recent database of hydrological and meteorological parameters for the entire Uttarakhand state. The comparison of recent discharge value of tube wells with the old data show that there is immense pressure on the groundwater reservoirs, and there is water scarcity in all the districts of Uttarakhand. The occurrence and distribution of water in the Himalayan region depend on the physiography, climatic conditions, vegetation, and geology of the river basins. In Uttarakhand, rainfall is the leading factor that controls the water availability and groundwater recharge. However, it is recorded that that the average annual rainfall is generally increasing, or is almost constant since the last decade. Therefore, the factors causing groundwater depletion needs attention such as the unsustainable utilization of water, natural calamities, land use/land cover changes in the form of deforestation and settlements that promotes high runoff and reduction of recharge area.

Quaternary deposits

Thick pile of fluvial, fluvio-glacial, glacial, lacustrine and gravitational sediments are referred as the Quaternary deposits. These deposits are significant because they host most human population and agricultural activities. They are also referred as hot spot for any geological disaster such as landslides or earthquakes. It is therefore vital to map these deposits in order to understand our development as well as disaster hotspots. The district-wise distribution of these deposits for the state of Himachal Pradesh is presented in the table 3.

Minerals and mining activities

The limited mining carried out in Himalaya is mostly the small scale mining by the private entrepreneurs. The open cast strip mining is commonly used practice for mining in the Himalayan region whereby a long strip of overlying soil and rock is removed. The underground mining earlier carried out for base metal minerals in Sikkim Himalaya and rock phosphate mines in Durmala and Maldeota near Dehradun are closed mainly because of the environmental reasons. The minerals occurrences reported from different states in the Himalayan region are: (a) Jammu and Kashmir: occurrences of coal, gypsum, limestone minerals. Sapphire (corundum), a precious stone is known to occur in Doda district of the state. (b) Himanchal Pradesh: occurrences of antimony, beryl, magnesite, gypsum, pyrite, rock salt, limestone and quartzite. (c) Uttarakhand: talc, magnesite and once limestone and phosphorite were important mineral that were mined in this state. There are occurrences of copper, lead and zinc. (d) Sikkim: important minerals reported are copper, lead, and zinc, other minerals are dolomite,

Table 3:

S. No.	District	Valley Fill (Area in km^2)	Flood Plains (Area in km^2)	River Terraces (Area in km^2)	Moraine Complex (Area in km^2)	Alluvial Fan (Area in km^2)	Piedmont Moraine (Area in km^2)	Hill Cut Terraces (Area in km^2)	Glacial Outwash Plain (Area in km^2)
1	Una	448.13	57.81	6.94	-	-	-	-	-
2	Kangra	1103.61	55.51	150.28	-	-	-	-	-
3	Chamba	23.08	8.41	33.76	34.75	0.53	-	-	-
4	Hamirpur	36	33	9	-	-	-	-	-
5	Bilaspur	27.12	5.46	5.72	-	-	-	-	-
6	Solan	218.21	5.58	0.26	-	-	-	-	-
7	Sirmour	179.86	52.58	29.77	-	-	-	-	-
8	Mandi	256.87	9.45	56.04	-	-	-	-	-
9	Kullu	117.71	8.51	17.71	41.15	8.03	34.11	-	-
10	Kinnaur	6.33	12.81	41.11	207.66	2.81	57.52	45.52	6.48
11	Lahaul & Spiti	19.51	109.44	55.85	426.87	101.14	237.74	28.04	9.22
12	Shimla	3.69	4.62	17.02	8.11		4.83		
	Himachal Pradesh	2440.12	363.18	423.46	718.54	112.51	334.2	73.56	15.7

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quartz, talc and limestone. (e) Manipur: imestone, chromite and china clay are known to occur, but mining is only of minor minerals. (f) Meghalaya: coal and limestone is reported from this state. (g) Mizoram: occurrences of lignite and pyrite are reported. (h) Nagaland: the reserve of coal resources are present. (i) Assam: well known for its oil field, and coal, limestone and sillimanite are reported. The major concerns of mining in Himalaya include: (i) no detailed prospecting is generally done prior to mining operations, (ii) lack of geological knowledge of the terrain in the mining groups. (iii) Height of the mine face are generally irregular, (iv) mining near roadsides may results landslides, (v) inappropriate practice of dumping of the mine waste in the adjacent streams/ fields, and post mining reclamation of land.

Mass movements

The inventory of active landslides and related mass movement activities for the states of Jammu & Kashmir, Himachal Pradesh and Uttarakhand had already been compiled were updated with the recent data. In addition, emphasis was on studying the landslide activities in the hilly township of Nainital (Uttarakhand), as the area had struck disastrous landslides along the Balia Nala. Therefore landslide susceptibility mapping for the entire township has been carried out using various bivariate methods. In order to assess the accuracy of the prepared LS maps, validation of the maps was carried out using success rate curve (SRC) and the prediction rate curve (PRC). Further it has been observed that landslide activities in the township has increased many-fold mainly because of the increased concentrated rainfall. Beside the area is tectonically active mainly because of the 'Balia Nala Fault / Lake Fault'. This demands that there must be a proper landuse policy in the township, taking into consideration the slope instability.

MoES Sponsored Project

Seismicity monitoring and evaluation of active faults in Garhwal Himalaya and adjoining Shimla hills region in Himachal Pradesh

(Ajay Paul)

Great earthquakes in the Himalaya have occurred repeatedly in the past and will continue to occur in the future but no great earthquake ($M > 8$) has taken place in the Central Himalaya over the past 300 years or more except the historically assessed major events ($M \sim 8.09$) of 1803 (Uttarkashi), in spite of the requisite strain build-up. The analysis of upper crustal earthquakes from the dataset 2007 to 2013 recorded by a seismic network (Fig. 88) installed in Garhwal and the adjoining region of Central Seismic Gap (CSG) in Northwest Himalaya has been carried out for spectral analysis and composite fault plane solutions.The epicentral locations of the micro-moderate size earthquakes in the Garhwal Himalaya have concentrated in a narrow zone trending parallel to the Main Central Thrust zone (MCT zone). Data analysis has been carried out to evaluate the probable depth of a great earthquake that is likely to happen in CSG. The source zone of these earthquakes is below the plane of detachment / MHT. By analyzing these events an attempt has been made to understand the characteristics of a probable source region, and the complexity of the probable future major earthquake in the seismic gap of the Garhwal-Kumaun region. The source parameters of 184 local events have been calculated and for these shallow focus earthquakes the seismic moment ranges from 2.40x10e11 to 4.23x10e14 Nm. The Mo (seismic moment) and Δs (stress drop) values are plotted against magnitude M respectively, which shows similar relationships with earlier work for these parameters for other workers for this region. The analysis shows that more than 65% of events have very low stress drop less than 1 bar. The maximum stress drop is found to be 33.77 bars for an earthquake of magnitude 4.8. Computation of composite fault plane solution has been carried out for 129 local earthquakes for M>1.8 with azimuthal coverage more than 180°-129 earthquake events are segregated in four clusters and their composite fault plane solutions are shown as c1, c2, c3, and c4 (Fig. 88). These source mechanisms indicate underthrusting perpendicular to the strike of the Himalayan arc and correspond to shortening in the south of the Higher Himalaya.

MoES Sponsored Project

Present day subsurface configuration and geodynamics of the Kumaon Himalaya: an integrated geophysical and geological investigation

(Devajit Hazarika, Gautam Rawat, Koushik Sen and Naresh Kumar)

Seismotectonics and earthquake source mechanism study in the Kumaon Himalaya

The Kumaon Himalaya falls under the Central Seismic Gap (CSG) of the Himalaya and provides a distinctive opportunity to study characteristics of the Himalayan fold-thrust-belt system. The region covers the highly seismically active Chiplakot Crystalline Belt (CCB), and other klippe structures viz. Askot and Almora Klippe. Geological evidence suggests that the CCB is a duplex slab within the Lesser Himalaya. Previous

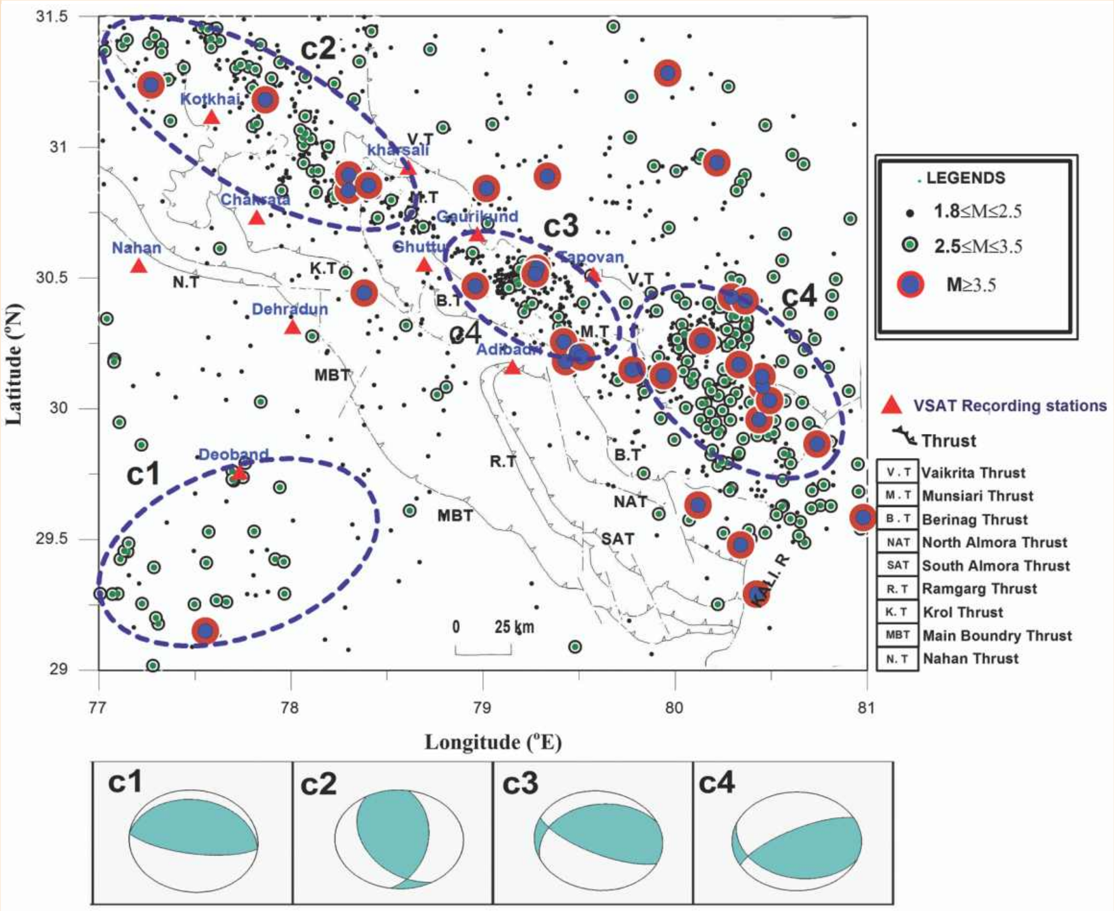

Fig. 88: Earthquake events plotted on the tectonic map of the region (●: 1.8≤M≤2.5, • ; 2.5≤M≤3.5 & ● M≥ 3.5). Composite fault plane solutions (c1,c2,c3,c4) for the 129 earthquake events are shown in four clusters respectively. (V.T-Vaikrita Thrust, M.T- Munsiyari Thrust, B.T-Berinag Thrust, NAT-North Almora Thrust, SAT-South Almora Thrust, R.T-Ramgarh Thrust, K.T-Krol Thrust, MBT-Main Boundary Thrust, and N.T- Nahan Thrust, Recording stations)

geological studies have reported the exhumation and deformation history of this duplex structure (Patel et al., 2007; 2009; 2011; Célérier et al., 2009). In this regard, a controversy between the rapid exhumation model (Avouac, 2003; Bollinger et al., 2004) and active out-of-sequence thrusting in the Himalayan wedge is persisted (Wobus et al. 2003; Hodges et al., 2004). A geological balanced cross-section and receiver function study indicate the presence of a ramp structure on the MHT beneath the CCB (Srivastava and Mitra 1994; Hazarika et al., 2020). Here within CCB, a cluster of dense seismicity is observed through recent data set (Hajra et al., 2019). Additional work on the earthquake source mechanism is very useful to characterize the sub-surface crustal deformation process and establish its linkage with tectonics.

An attempt has been made to address this issue using local earthquakes data of 2016 to 2019 recorded by 18 broadband seismic (BBS) stations located in the Kali river valley and adjoining area (Fig. 89). Also, well-located events are extracted from the ISC-EHB catalog to strengthen our results. The seismicity in this eastern part of the Kumaon Himalaya diverse from the usual high concentrated seismicity within the so-called Himalayan Seismic Belt (HSB). Instead, a cluster of seismicity is located in the CCB immediately south of the Vaikrita Thrust. This is also shallow focused upper crustal seismicity but it is located to the southern part of the HSB. The seismicity to the north of the Vaikrita Thrust is extremely less. The region also experienced several earthquakes of M ≥5.0 in the recent past. Earthquake focal mechanism solutions (FMS) provide key information of seismic sources which are computed by this data using a highly reliable technique of waveform inversion. A multistep inversion approach of Cesca et. al. (2010, 2013) is adopted which is suitable for the automated moment tensor (MT) inversion of the extended source parameters. In this, both time and

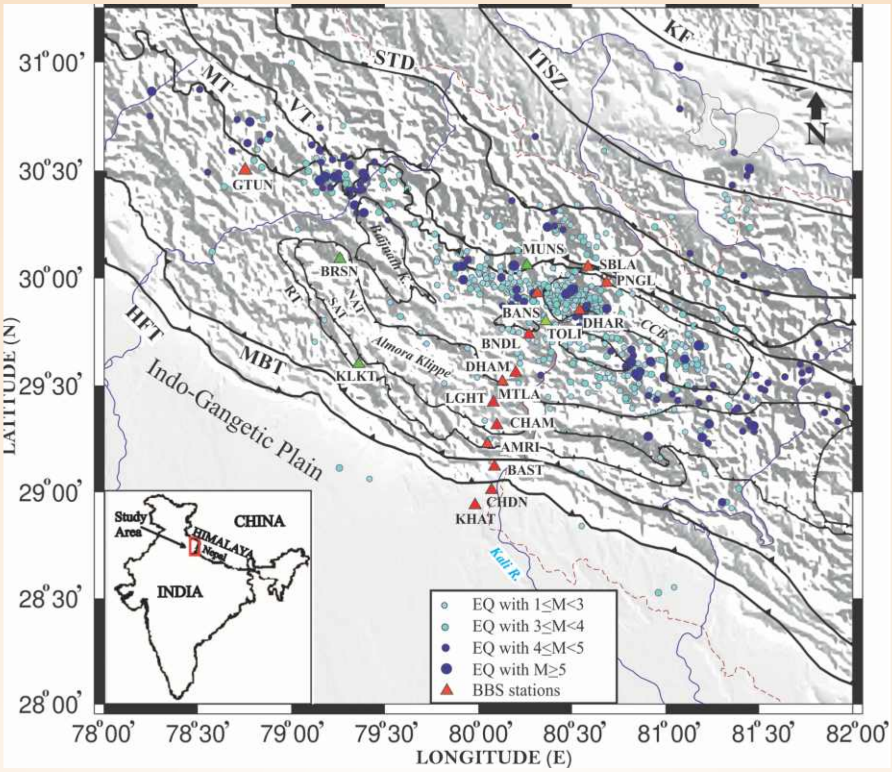

Fig. 89: Spatial distribution of earthquakes in the Kumaon Himalaya and adjacent region depicting earthquakes from the present study as well as ISC-EHB catalog (http://www.isc.ac.uk/iscbulletin/search/catalogue/). The background tectonic map is modified after Srivastava and Mitra (1994). The tectonic features viz. HFT-Himalayan Frontal Thrust, MBT-Main Boundary Thrust, RT-Ramgarh Thrust, SAT-South Almora Thrust, NAT-North Almora Thrust, MT-Munsiari Thrust, VT-Vaikrita Thrust, STD- South Tibetan Detachment, ITSZ-Indo-Tsangpo Suture Zone, KF-Karakoram Fault are shown. The major Klippe structures, e.g. Chiplakot Crystalline Belt (CCB), Askot (ASK), Almora, and Baijnath are represented in italic. The earthquakes with different magnitudes are colour coded according to magnitude (legends are shown in the bottom left corner). The broadband seismological stations of WIHG, Dehradun, and Kumaon University are shown by red and pink triangles respectively. The inset (bottom left) marks the study area with respect to the India map.

frequency domain modeling at successive inversion steps are used to retrieve the source parameters. Computation steps adopt a suitable range of frequencies, norm definitions for misfit calculations, and suitable parametric spaces. The method uses a kinematic model to compare both double couple (DC) and full MT source models. We select 40 earthquakes for FMS analysis based on the data of high signal to noise ratio (SNR), a clear record of different phase arrivals and magnitude M $\geq$3.5. The seismic waveform data has been pre-processed following Cesca et al. (2010) to ensure quality control (to exclude gaps, spikes, etc.), removal of mean and trend, deconvolution to remove the instrumental response, integration to obtain displacement traces, bandpass filtering and tapering in the time domain. Instrument correction was applied to accurately remove the instrument response over a wide frequency band with different selection criteria. Each event is processed by a minimum of 3 stations data depending upon the time period and continuity of the operation of these stations, with a maximum of up to 10 stations.

The focal mechanism solutions show a complex stress pattern associated with the clustered seismicity. Careful examination of the orientations of inferred fault planes of focal mechanisms suggests the presence of a hinterland dipping Lesser Himalayan Duplex (LHD) over the ramp structure on the Main Himalayan Thrust. The high compressive stress and deformation rate in the CCB is partially accommodated by this duplex structure. The large concentration of shallow focus crustal earthquakes in the CCB may be the result of the presence of fluid rich zone as well as strain localization and large stress build-up on the ramp structure of the Main Himalayan Thrust beneath the CCB as observed in our receiver function image reported earlier.

MoES Project

Comparative study of weathered/ soil profiles developed on Granitic and Basaltic rocks of Higher and Lesser Himalaya in Garhwal region: Implication on climate-tectonic interaction.

(Pradeep Srivastava and R. Islam (retd.))

Physical, chemical, and biological processes decompose and disintegrate the rocks on the Earth's surface and produce a porous zone of residues and dissolved constituents. Meteoric water and atmospheric gases interact with the bedrock in this zone and serve as the source for soils and sedimentary rocks and primary habitat for terrestrial life. Other geological processes including the consumption of greenhouse gas CO_2, development of residual mineral deposits, landscape evolution, and release of nutrients help in regulating the climate and hence make weathering crucial to study. The project is initiated in the month of October and the literature survey, recruitment of JRF are completed. The literature survey could suggest the international status of the subject which include the studies of the composition of weathered rock/soil profiles, the implication of dissolution and secondary precipitation on major and minor elements, comparative studies of different weathering profiles to elucidate the controlling factors, various approaches to quantify the weathering rate and many. This project aims to study weathering profiles developed on granitic and basaltic rock will be examined from two areas (Lesser Himalaya and Higher Himalaya) having different climatic and tectonic conditions. Elemental comparison between profiles developed on similar strata from two different climatic conditions will be followed to interpret the climatic controls on elemental distribution within the weathered zone and between profiles developed on different rock strata in single climatic conditions will be followed to elucidate the mineralogical controls on elemental distribution. For a sustainable ecosystem, it is vital to understand how fast the rocks are weathering away i.e. the weathering rate. The weathering rate in different climatic-tectonic conditions will also be examined within this project. Towards this complete drainage map and slope map of the area is prepared and analyzed.

CSIR-Emeritus Scientist Project

Regional variability in climate over the past two millennia using multi-proxy tree-ring records and climate change impact on high elevation plant species in Himalaya

(R.R. Yadav)

Tree ring data of Himalayan cedar (*Cedrus deodara*) collected earlier in 2016 and 2017 from moisture stressed ecological settings in Kishtwar, Jammu, and Kashmir were analyzed. Seven site chronologies having strong precipitation signals were used to develop Jhelum discharge extending back to AD 1559. The reconstruction revealed high inter-annual to inter-decadal variations in river discharge. Late 16th-early 17th century/early 19th century experienced low/high discharge. The reconstructed river discharge is directly associated with the precipitation variations in the region. The reconstruction also revealed close similarity with other tree-ring based reconstructions of Satluj and Indus flow.

MoES Sponsored Project

Geochemistry and Geochronology of the Tethyan ophiolites of the Indo-Myanmar Orogenic Belt, Northeast India: Geodynamic and petrogenetic implications and mineralization

(A.K. Singh and Rajesh Sharma)

The Nagaland-Manipur Ophiolite (NMO) of Indo-Myanmar Orogenic Belt (IMOB), northeast India which is believed as remnant of Neotethyan oceanic lithosphere has become a hotly debated ophiolite section of Indian plate margin. Though the crustal units of this ophiolite show diverse geochemical features equivalent of mid-ocean ridge basalts (MORB), ocean island basalts (OIB), an island arc tholeiites (IAT), tectonic discrimination based on the petrological characteristics of mantle rocks have not been properly defined.

Our detailed geological field and petrological studies on crustal rocks and mantle sequence of the NMO have led to the conclusion that two distinct differences between the subduction-related group and the non-subduction related group are encountered in the NMO. The petrological and geochemical evidences for these groups are summarized as Non-subduction groups: (i) The non-subduction type of mafic rocks has a compositional range of high-Ti alkaline OIBs to low-Ti MORBs enriched in LILE and HFSE (Fig. 90). They might have formed during the Late Jurassic to Early Cretaceous period by a divergent force when the Indian plate was initially separated from Antarctica and Australia. (ii) This group consists of melts derived from a plume source (possibly similar to Kerguelen plume) and depleted N-MORB source. (ii) Upper mantle rocks (lherzolite and harzburgite) supposed to be residual products of high degree partial melting of upper mantle at a spreading zone. However, it is not sure whether they could be residual parts of the OIB group. (iv) The presence of a high-Al spinel and their Cr# in spinel and Fo content in olivine in the peridotite and dunite

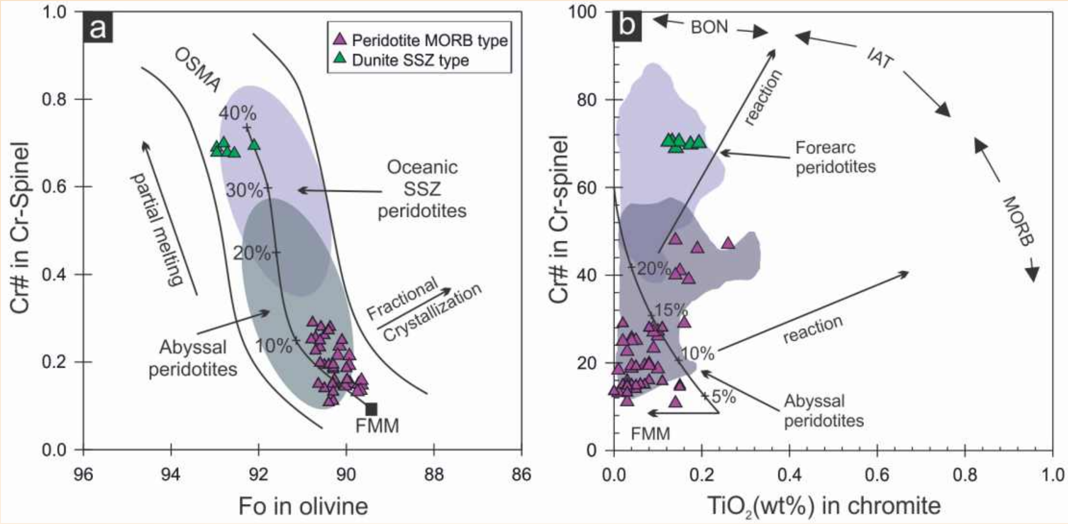

Fig. 90: (a) Cr# in spinel versus Fo content of olivine in ultramafic rocks from NMO. (b) The Cr# vs. TiO_2 plot for spinel showing the degree of melting of mantle rocks and reaction trends with boninite melts, island arc, and MORB melts.

samples (Fig. 90a, b) ultimately supports the non-subduction origin of the NMO.

Subduction groups: (i) The mafic rocks of subduction origin are tholeiitic, low Ti, LREE, and HFSE depleted in nature and they represent fore arc magma. We propose that they were formed much later, probably around by the end of early Cretaceous and the beginning of late Cretaceous. (ii) Their depleted nature of LREE, low ratio of Nb/Yb<1 suggest that magma was generated by partial melting of depleted mantle wedge due to a decrease in solidus temperature as hydrous fluid was released from the downgoing slab of the Indian plate and added to the overlying mantle wedge with no input of melt from the slab. (iii) The availability of high-Cr in spinel in chromitites and highly depleted dunite in the NMO also correspond to subduction origin (Fig. 90a, b). (iv) The timing of the formation of this group is equivalent to other neighboring ophiolite sections of Kalayamo and Chin hills of Myanmar and Andaman in India.

Combining all the available data of mineral and elemental chemistry in conjunction with the new petrology and field evidence, we confirm in the NMO of Northeast India is a unique ophiolite section, which tends to preserve two sets of a genetically different magmatic suite of rocks: 1) anhydrous, mid-ocean ridge+plume type. 2) hydrous, supra-subduction zone-type, which were formed at different time scales, but somehow they are co-existing now along the tectonically deformed mountain belt of the IMOB. It is also proposed that the NMO has the signature of both subduction and non-subduction ophiolite rocks, which were formed due to multiple stages of magmatic episodes over a wide range of geological timescale; starting from east Gondwana separation (Late Jurassic-Early Cretaceous) to eastward subduction of Indian plate under Myanmar plate at late Cretaceous. Therefore, the evolution of NMO was not an easy-going process and is not as simple as previously thought of as a normal subduction process. It preserves a record of both the formation and closing of the Tethys Sea.

MoES Sponsored Project

Evaluating conditions of deformation during subduction and exhumation of the north Indian continental margin: A study based on structure and crystallographic features of the Tso Morari Dome of trans-Himalaya, Ladakh, India

(Koushik Sen and A. K. Singh)

The India-Eurasia collision zone in eastern Ladakh, India is marked by the Tso Morari Gneiss dome that underwent continental subduction, ultra-high pressure metamorphism and rapid exhumation during the Himalayan orogeny. This dome is characterized by retrograded eclogitic enclaves. Seismic studies have shown that this collisional zone is characterized by a cluster of seismicity at 30 to 50 km depth and also a low velocity zone at 20 to 30 km, which in fact, is ubiquitous in the Himalaya. Considering the Tso Morari Crystallines (TMC) metabasics as representative of the present day Indian lower crust, we carried out detailed petrography, mineral chemistry and P-T pseudosection modelling of one metabasics sample from the western margin of the TMC to understand seismotectonics of the Indian middle crust. Petrographic observations reveal lawsonite pseudomorphs with radial cracks and plagioclase-pyroxene-amphibole symplectites. P-T pseudosection suggests peak-metamorphism at 2.4-2.5GPa and 500-520°C followed by an isothermal decompression path till 1.4GPa and eventually granulite grade metamorphism at 0.7GPa and 700-740°C. We infer that mid-crustal earthquakes in the Indo-Eurasian collision zone is caused by breakdown of lawsonite due to rapid exhumation of the lawsonite-eclogite Indian lower crust. Water expelled from lawsonite during exhumation to form epidote and subsequent granulite metamorphism created a low velocity zone at 20 to 30 km depth.

WoS-A Scheme DST

AMS, microstructures, geochemistry, thermometry and chronology of Dalhousie Granite, Western Himalaya, focusing on the granite emplacement and exhumation

(Kavita Tripathi)

The early Paleozoic granitic rocks are mostly restricted to the HHC wherein they occur as layers of augen gneisses or as intrusives emplaced around 476 Ma at relatively high structural levels within the Proterozoic Haimanta Group. The studied Dalhousie granite is well exposed in the Dalhousie town which is situated in the NW of Dhauladhar range in Himachal Himalaya.

The field and laboratory based studies of the granite suggests that the two mica bearing granite is showing undeformed as well as deformed nature of the granite. At certain places near northern margin of granite south of mangla village and along the southern contact of granite from Mahela towards chamba shows sharp intrusive nature with the associated metasedimentary of the Salkhala Group. Towards the Mahela the aplitic nature of the granite is also observed. The small scale shear sense indicator suggests the top towards West movement of the shearing.

The microstructural studies of the Dalhousie granite show dynamic recrystallization and high temperature deformation fabric structures in quartz and plagioclase, which is followed by low temperature deformation fabric. The geochemical characters of the Dalhousie granite suggest it is paraluminous S- type granite and a tectonic discrimination diagram shows syncollision tectonic environment of its formation.

The fluid inclusion petrography suggests four different types of inclusions present in the quartz grains. The inclusions are primary as well as secondary in nature. They are mostly isolated and disseminated in origin. The composition varies from high saline, carbonic aqueous to aqueous.

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47. Paul, Arpita, Hazarika, Devajit, Kumar, Naresh & Wadhawan, Monika 2020: Upper mantle anisotropy in the northwest Himalaya and Ladakh-

Karakoram zone based on SKS splitting analysis. Journal of Geodynamics (Under review).

48. Penna, I., Hermanns, R., Nicolet, P., Morken, OA., Dehls, J., Gupta, V., & Jaboyedoff M. : Airblasts caused by large slope collapses. GSA Bulletin (Communicated).

49. Pundir, S., Adlakha, V., Kumar, S. & Singhal S. 2020: Closure of India-Asia collision margin along the Shyok Suture Zone in the eastern Karakoram: new geochemical and zircon U-Pb geochronological observations. Geological Magazine (Online) (In press).

50. Pundir, S., Adlakha, V., Kumar, S., Singhal, S. & Sen, K.: Petrology, geochemistry and geochronology of granites and granite gneisses in the SE Karakoram, India: Record of subduction-related and pre-to-syn-kinematic magmatism in the Karakoram Fault Zone". Mineralogy and Petrology, (In-press).

51. Quasim, M.A., Ghosh, S.K., Ahmad, A.H.M. & Srivastava, V.K. 2020: Integrated Approach of Lithofacies and Granulometric Analysis of the Proterozoic Upper Kaimur Group sediments of Vindhyan Supergroup, Son Valley, India: Palaeo-environmental implications. Geological Journal (Wiley), (Accepted).

52. Quasim, M.A., Khan, Shaista, Srivastava, V.K. Ghaznavi, A. Ahmad & A.H.M. 2020: Role of cementation and compaction in controlling the reservoir quality of the Middle to Late Jurassic Jara Dome Sandstones, Kachchh Basin, Western India. Geological Journal (Wiley), doi: 10.1002/gj.3781 (Under revision).

53. Ram, P., Gupta, V., Devi, M. & Vishwakarma, N. 2020: Landslide susceptibility mapping using Bivariate Statistical method for the hilly township of Mussoorie and its surrounding areas, Uttarakhand Himalaya. Journal of Earth System Science (In press).

54. Ramola, N., Sundriyal, Y.P., Puniya, M.K., Gupta, V.: Large scale mapping and to assess active and potential landslide zones between Sonprayag to Kedarnath using geomorphic and kinematic analysis method. Himalayan Geology (Communicated).

55. Rawat, V., Rawat, S., Srivastava, P., Negi, P.S., Prakasam, M., Kotlia, B. & Sinha, A.: A 6000 Year Indian summer monsoon variability record from an alpine paleolake of Higher Central Himalaya, India. Quaternary Science Reviews (Communicated).

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57. Saravanan, P., Gupta, A.K., Zheng, H., Santosh K., Rai & Panigrahi, M.K. 2020: Changes in deep-sea oxygenation in the northeast Pacific Ocean during 3210 kyr BP, Geophysical Research Letters (Communicated).

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61. Shukla, V., Chauhan, Vishal, Kumar, Naresh & Hazarika, Devajit 2020: Assesment of Rn-222 continuous time series for the identification of anomalous changes during moderate earthquakes of the Garhwal Himalaya. Applied Radiation and Isotope (Under review).

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63. Singh, J., Yadav, R.R., Negi, P.S. & Rastogi, T. 2018: Sub-alpine trees testify late 20th century rapid retreat of Gangotri glacier, Central Himalaya. Quaternary International Reviews (Communicated).

64. Singh, Jayendra, Yadav, Ram R., Negi, Pyar S. & Rastogi, Tanupriya 2018: Sub-alpine trees testify late 20th century rapid retreat of Gangotri Glacier, Central Himalaya. Quaternary Science Reviews (Communicated).

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70. Singh, Rakesh, Paul, Ajay, Shalini, Joshi, Pradeep, Kumar, Sushil, Tiwari, Anil & Singh, Tejpal 2019: Reverse migratory behaviour of the earthquakes aftershock sequences along Himalayan Seismic Belt, Northwest Himalaya. Journal Quaternary International (Under review).

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75. Srivastava, V.K. & Aggarwal, A. 2019: Middle Eocene regressive phase evident in the uppermost part of the Harudi Formation, Kachchh Basin, Western India. Carbonates and Evaporites (Springer), (Accepted).

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77. Suresh, N. & Kumar, R. 2020: Late Quaternary Deflections of the Beas-Satluj rivers at the Himalayan mountain front, Kangra re-entrant, India: response to fold growth and climate. Jour. Asian Earth Sci., 191. (Online) (In press).

78. Thena, T., Mohan, K., Prakasam, M., Saravanan, K. : Early-Middle Pleistocene productivity changes in Northern Cascadia Margin. Pacific Ocean Deep-Sea Research Part-I **(**Under review**).**

79. Thena, T., Mohan, K., Prakasam, M., Saravanan, K.: Paleoecological significances of deep-sea benthic foraminifera from methane rich sediments of Cascadia Margin, North East Pacific Ocean CRPALEVOL (Under review).

80. Tiwari, Anil, Paul, Ajay Singh, Rakesh & Upadhyay, Rajeev 2020: Asperity interaction and dependence of frequency-size distribution of earthquakes in brittle-ductile transition zone of NW Himalaya. Journal GRL (Communicated).

81. Yadav, R.R. & Singh, J. : Tree-ring-width chronologies from moisture stressed sites fail to capture volcanic eruption associated extreme low temperature events. Current Science (Communicated).

82. Yadav, R.R., Negi, P.S. & Singh, J. : Climate Change and Plant Biodiversity in Himalaya, India.

Proceeding of Indian National Science Academy (PINSA) (Communicated).

83. Zhou, R., Aitchison, J.C., Lokho, K., Sobel, E.R., Feng, Y., Zhao, J.X.: Unroofing the Ladakh batholiths: constraints from autochthonous molasse of the Indus basin, NW Himalaya. Journal of the Geological Society (in press).

Book Edited and Chapters published

1. Gupta, A.K., Prakasam, M., Dutt, S., Clift, P.D. & Yadav, R.R. 2020: Evolution and Development of the Indian Monsoon. *In*: Geodynamics of the Indian. Plate Springer, Cham, 499-535, doi.org/10.1007/978-3-030-15989-4_14.

2. Sain, K. & Kumar, P.C. 2019. Human and Machine: an amalgamation to aid seismic interpretation. ONGC Bulletin, 54(2), 1-14.

3. Sain, K. & Kumar, P.C. 2020. Effectively interpreting seismic data for voluminous geo-resources. DEW Journal, February Issue, 29-34.

4. Sain, K. & Kumar, P.C. 2020. Seismic, Artificial Intelligence to Neural Intelligence for Advanced Interpretation. In: Gupta, H.K. (ed.), Encyclopedia of Solid Earth Geophysics, 3rd Edition. Springer, The Netherlands (In press).

5. Sain, K. 2019. Controlled source seismology in India in the 21st century. In: Gupta, Harsh K. (ed.), Proceedings of the Indian National Science Academy, 1919-2019 Centennial Celebrations of the International Union of Geodesy and Geophysics (IUGG), Contributions from India, 85(2), 453-468.

6. Sain, K., Sharma, R., Kumar, S., Dobhal, D.P., Gupta, V., Srivastava, P., Perumal, R.J.G. & Lokho, K. 2020. Research status at Wadia Institute of Himalayan Geology (WIHG), Dehradun during 2015-2019. *In:* Banerjee, D.M. & Bajpai, Sunil (eds.), Proceedings of the Indian National Science Academy, 2015-2019. 86(1), 721-745.

7. Sharma, R., Villa, I. & Kumar, S., 2020, Crustal architecture and evolution of the Himalaya KarakoramTibet Orogen. Edited Geological Society of London Special Publication v. 481, 386pp.

8. Sharma, Rajesh, Vila, Igor M. & Kumar, Santosh (eds.) 2019: Crustal Architecture and Evolution of Himalaya-Karakoram-Tibet'. Geological Society, London, Special Publication, 481: doi:org/10.1144/SP481.

9. Shukla, A., Garg, S., Kumar, V., Mehta, M. & Shukla, U.K. 2020: Sensitivity of Glaciers in Part of the Suru Basin, Western Himalaya to Ongoing Climatic Perturbations. Edited Chapter, 351-377. *In:* Dimri, A., Bookhagen, B., Stoffel, M., Yasunari, T. (eds.), Himalayan Weather and Climate and their Impact on the Environment. Springer, Cham.

10. Singh, P., A., Ao, S.S., Thakur, Rana, S., Sharma, R., Singh, A.K. & Singhal, S. 2020: Geology, Structural and Metamorphic studies along the Mandi-Kullu-Manali-Rohtang section of Himachal Pradesh, NW-India The Field excursion in the Himalayan ranges, Springer Publication (Editors: S. Mukherjee and others), New York. (Chapter-Book) (Accepted).

11. Trivedi, S., Kumar, P., Parija, M.P. & Biswas, A. 2020: Global Optimization of Model Parameters from the 2-D Analytic Signal of Gravity and Magnetic Anomalies Over Geo-Bodies with Idealized Structure. Advances in Modeling and Interpretation in Near Surface Geophysics, 189-221.

12. Vedanti, N., Vadapalli, U. & Sain, K. 2020. A brief overview of CBM Development in India. *In:* Banerjee, D.M. & Bajpai, Sunil (eds.), Proceedings of the Indian National Science Academy, 2015-2019. 86(1), 721-745.

Technical Reports

1. Prepared and submitted a technical Report on the work carried out titled "Geophysical Investigation along with the alignment of silt flushing tunnel (SFT) at Tapovan Vishnugad, NTPC, TVHPP, JOSHIMATH", under the consultancy awarded by NTPC Limited, Tapovan Vishnugad (2019-20) (A Govt. of India Enterprise).

SEMINAR/SYMPOSIA/WORKSHOP ORGANIZED

3rd NGRSM Report (06-08, June 2019)

The Institute organized 3rd National Geo Research Scholars Meet to encourage young research scholars working in the field of Geology across the country to present their scientific contribution and research idea on an open platform and also provide an opportunity to interact with the renowned geoscientists of the country. The events started on 6th June 2019 with an inaugural function, wherein Director welcomed the Chief Guest. Smt. Anju Bhalla*, Joint secretary of Dept. of science and Technology, Guest of honour* Dr. Rajendra Dobhal, *Director, UCOST*, Chairman Dr. Kalachand Sain, Director WIHG and Co-Chairman Dr. Rajesh Sharma, WIHG. The introduction and the background note of the program was given by Dr.S.K. Tiwari (Convenor of the event). It was followed by the address of Guest of Honour and the Inaugural address by the Chief Guest.

The inaugural key note lecture was delivered by Prof. Pulak Sen Gupta on the topic "A Marvelous marble: A geologists Perspective". Several other keynote lectures on various topics related to themes of the event were delivered by the distinguished renowned professors/scientists of the country namely Prof. Parmesh Banerjee (Technical Director at the Earth Observatory of Singapore), Prof. A.K. Gupta (IIT Kharagpur), Prof. Sunil Bajpai (IIT Roorkee), Prof. Sarajit Sensarma (University of Lucknow), Dr. Kalachand Sain (WIHG).

The four days long event included field trip and paper presentation under five major themes, which include: (i) Geodynamics of fold and Thrust belt (ii) *Natural Hazards* (iii) Climate Change (iv) Sedimentation and Tectonics (v) Natural Resources and Ecosystem. A total of 33 Oral presentations and 135 Poster presentations were made during the meet. The event was attended by 168 research scholars from 40 different organizations, including research institutes Universities, IITs, and IISERs. The technical session ended with a vote of thanks by Dr. Pinkey Bisht (Convenor of the event). After which a half day field excursion has been conducted to show the signature of the HFT near Mohand, Dehradun. During the event, the young researchers were also showcased and demonstrated with the available analytical facilities of the institute. Also, to encourage researchers, awards were given to the best oral and poster presentations. A cultural event was also organized for the participants in the evening.

AWARDS AND HONOURS

- Dr Pradeep Srivastava received Anni Talwani Gold Medal of Indian Geophysical Union, October 2019.
- Dr (Mrs) Chhavi Pant Pandey has been awarded Young Scientist Award for best Oral presentation, during 14th Uttarakhand State Science and Technology Congress 2019-2020 (27th-29th February, 2020 at UCOST, Vigyan Dham, Dehradun).
- Prof. Kalachand Sain is conferred with Sriram Srinivasan Award (2018) received in 2019, by Association of Exploration Geophysicists.
- Prof. Kalachand Sain is conferred with Prof. Jagdeo Singh Memorial Best Paper Award (2018), received in 2019, by Geological Society of India.
- Dr Perumal Sami received INSA Visiting Scientist Fellowship 2018-19.
- Sushil Kumar, Anil Tiwari & team Won Second prize in the poster presentation titled "Source parameters and moment tensors of four earthquakes (Mw: 3.7 - 4.4) triggered in the Kishtwar Region, India" in the National conference on "Earthquake: Investigation and Instrumentation" organized by the CSIR-Central Scientific Instruments Organization, Chandigarh in CSIR-CSIO Auditorium during 23-24 Sept., 2019.

VISITS ABROAD

- Dr A.K. Singh visited Muscat, Oman, during January 12-14, 2020 for attending International Conference on Ophiolite and Oceanic Lithosphere.
- Dr Pradeep Srivastava visited Dublin, Ireland to Attend International Quaternary Union 23-30th July 2019 and presented a paper on Paleoflood Records of Ladakh Himalaya.
- Dr Suman Lata Rawat: attended and Presented research work on the title "Mid to late Holocene changes in the Indian Summer Monsoon: a multi proxy record from the Bhagirathi valley, Northwest Garhwal Himalaya", 20th Congress of the International Union of Quaternary Research (INQUA) 2019, Dublin, Ireland, July 25-31.
- Dr Sushil Kumar Visited Singapore to attend the 16th General Meeting of "The Asia Oceania Geosciences Society (AOGS)" held during on 28 July to 2 August, 2019 and Convened & Chaired Session on "SE14 on Active Tectonics, Faults and Large Fast & Slow Earthquakes" and to present two research papers (orally) titled "Source Parameters and Moment Tensors of the February 06 2017 Mw5.7 Garhwal Himalaya, Earthquake, India" and "Machine Learning and Wireless Sensor Networks for Earthquake Data Analysis in Real Time". (Sushil Kumar)
- Dr Kalachand Sain and Dr Vikram Gupta visited Norway during June 10 -15, 2019 to attend Indo-Norwegian workshop on the Norwegian Experience with hazard mapping of large rock slope instabilities within the ambit of the MoES funded project "Landslide hazard assessment in NE India along the Gangtok-Tsomgo/Changu Lake and Gangtok / Chungthang - Lachen Corridors"
- Dr Kapesa Lokho visitied Yangon, Myanmar and presented a paper on "Fossils of Indo-Myanmar range" in MAESA Second International Conference on Applied Earth Sciences in Myanmar and Neighbouring Regions 29/30 November1 December 2019.

PH.D. THESES

Name of Student	Supervisor	Title of the Theses	University	Awarded/ Submitted
Priyanka Singh Rao	Dr R.J. Perumal Dr A.K. Sharma	Surface Rupture Investigations of the 1950-Meisoseismal Zone of Assam Earthquake along Himalayan Foothill Zone, Arunachal Pradesh-Assam Himalaya	Kumauan University, Naintial	Awarded (Sept. 2019)
Radhika Sharma	Dr A.K. Singh Dr Naresh Kumar	Comparative Study of Geology and Geochemistry of Devsar and Khanak Area, District Bhiwani (Haryana), India	Kurukshetra University, Haryana	Awarded
Poonam Chahal	Dr Pradeep Srivastava Prof. Y.P. Sundriyal	Late Pleistocene landscape of Zanskar River valley (Ladakh Himalaya): implication to sediment storage and river connectivity.	HNB Garhwal University, Srinagar	Awarded
Arun Prasath	Dr Ajay Paul Prof. Sandeep Singh	Seismotectonics of Garhwal Himalaya between Alaknanda and Yamuna Valleys	IIT Roorkee	Awarded (Oct. 2019)
Rakesh Singh	Dr Ajay Paul Prof. Y.P. Sundriyal	Source Charaterization of the seismicity in the Garhwal Himalaya and its manifestation in the study area	H.N.B. Garhwal University, Srinagar	Awarded (Sept. 2019)
Divya Thakur	Dr S.K. Bartarya Dr H.C. Nainwal	Hydrogeological studies of intermountain basin of Una district, HP with special reference to impact assessment of environmental change	H.N.B. Garhwal University, Srinagar	Awarded
Imlirenla Jamir	Dr. Vikram Gupta Prof. G.T. Thong	Slope Stability Analyses on the Yamuna Valley, Garhwal Himalaya	Nagaland University, Kohima	Awarded
Vipin Kumar	Dr. Vikram Gupta and Prof. Y.P. Sundriyal	Landslide Susceptibility Zonation and Slope Stability analyses between Moorang and Rampur, Satluj valley, Himachal Pradesh	H.N.B. Garhwal University, Srinagar	Awarded
Manju Negi	Dr S.K. Rai Dr. Udai Bhan	Petrographic and Isotopic Studies of the Precambrian Lesser Himalayan Clastic Sediments: Implication for their Provenances	University of Petroleum and Energy Studies, Dehradun	Awarded (Aug. 2019)
Zuhi Khan	Dr H.K. Sachan Prof. A.H.M. Ahmad	Facies analysis, petrography and diagenesis of middle to late Jurassic Jumara Dome sediments, Kachchh, Gujrata	AMU, Aligarh	Awarded
Purushottam Kumar Garg	Dr Aparna Shukla Prof. A.S. Jasrotia	Assessment of variable response of Himalayan Glaciers using geospatial techniques	Jammu University, Jammu	Awarded Sept. 2019
J.N. Moiya	Dr Ashing Luirie Prof. G.D. Thong	Tectono-geomorphic evolution of the intermontane basins and Quaternary deformation in the schuppen belt in parts of Dimapur and Peren districts, Nagaland.	Nagaland University Kohima	Awarded Jan. 2020

S. Khogenkumar Singh	Dr A.K. Singh Prof. Santosh Kumar	Petrology and Geochemistry of Mafic and Ultramafic Rocks of the Central part of Nagaland-Manipur Ophiolite Complex, Northeast India	Kumaun University, Nainital	Submitted
Jairam Singh Yadav	Prof. R.B.S. Yadav Dr D.P. Dobhal	Glacier Mass Fluctuations and Meteorological Parameters: Implications for Regional Climate	Kurukshetra University, Kurukshetra	Submitted
Simran Singh Kotla	Dr R.K. Sehgal Prof. Rajeev Patnaik	Reconstruction of palaeoecology and palaeoclimatology using stable carbon and oxygen isotopes of pedogenic clays, molluscan shells and mammalian dental enamel from Siwalik sequences exposed between Ghaggar and Markanda river valleys (Haryana, India)	Panjab University, Chandigarh	Submitted June 2019
Diwate Pranaya Rameshwar Rao	Dr Narendra Meena Dr Sandeep Pandita	Holocene palaeoclimate record from Renuka Lake, Himachal Pradesh, India	Jammu University, Jammu	Submitted
Purbojoti Phukon	Dr Koushik Sen Prof. H.B. Srivastava	Geochronology and Geochemistry study of Kumaun Himalayan rock, NW India	BHU, Varanasi	Submitted
Somya Jana	Dr. Kalachand Sain	Stochastic Modeling of Gas Hydrate Reservoirs	IIT(ISM), Dhanbad	Submitted

PARTICIPATIONS IN SEMINARS / SYMPOSIA / MEETINGS

- Dr R.K. Sehgal attended the International Advisory cum Interaction Meet for the establishment of the Indian Museum of Earth (TIME), held at INSA, New Delhi during March 31 to April 2, 2019.
- Dr P.S. Negi participated in Forest fires mitigation meeting/workshop, Govt. of Uttarakhand, Dehardun, on April 16, 2019.
- Drs Vinit Kumar, Manish Mehta and Aparna Shukla attended the C2E2 Himalaya International workshop held at Indian Institute of Technology, Mandi during April, 18-20-2019.
- Dr. Santosh K. Rai attended the Committee meeting constituted for the revision of the mission Document of National Water Mission (NWM) at the Ministry of Water Resources, River Development & Ganga Rejuvenation, New Delhi on June 6, 2019.
- Dr Suman Rawat attended the SERB 1st Group monitoring meeting for earth and atmospheric sciences, at IIT Guwahati, Assam during June 6-7, 2019 and presented the paper entitled "Holocene centennial to millennial scale changes in Indian summer monsoon: a multi proxy record from high altitude regions of Uttarakhand Himalaya".
- Dr Vineet K. Srivastava attended the 3rd NGRSM and presented a paper entitled "Depositional model for the first report of late middle Eocene dolostone succession of Kachchh Basin, western India" at WIHG, Dehradun during June 6-8, 2019.
- Dr Suman Rawat attended the 20th Congress of the International Union of Quaternary Research (INQUA-2019), Dublin, Ireland during July 25-31, 2019 and presented the papers entitled "Mid to late Holocene changes in the Indian Summer Monsoon: a multi proxy record from the Bhagirathi valley, Northwest Garhwal Himalaya" and "A ~6000year high resolution continuous paleoproductivity and paleoenvironmental record reconstructed from the paleolake sediments of Pinder valley, Garhwal Himalaya".
- Dr Sushil Kumar attended the 16th General Meeting of "The Asia Oceania Geosciences Society (AOGS)" held during on 28 July to 2 August, 2019 in the Suntec Singapore Convention & Exhibition Centre, Suntec City, Singapore and presented two research papers (orally) titled "Source Parameters and Moment Tensors of the February 06 2017 Mw5.7 Garhwal Himalaya, Earthquake, India" and "Machine Learning and Wireless Sensor Networks for Earthquake Data Analysis in Real Time".
- Dr Rajesh Sharma acted as Guest of Honour in the inaugural function of International conference on "Information Technology and Management for the Sustainable Development" (ICITMSD-2019) during August 9-10, 2019 and delivered a talk on the "Information Technology: Multidisciplinary Scopes in Academics".
- Dr Suman Rawat attended PAGES LandCover6K working group meeting "Pollen based estimates of past land cover in South and Southeast Asia: A first evaluation of results, methods and new approaches in view of climate (and paleoclimate) models incorporating the monsoon system", at French Institute of Pondicherry, Pondicherry during September 11-14, 2019.
- Dr Sushil Kumar attended National conference on "Earthquake: Investigation and Instrumentation" at CSIR-Central Scientific Instruments Organization, Chandigarh during Sept. 23-24, 2019.
- Dr. Santosh K. Rai *delivered a popular lecture* in Hindi Pakhwara on the topic on "Bhartiya Bhoobhag me Sathit Uttar-Paschim Himalaya ke Garm Srot" at WIHG Dehradun held on September 24, 2019.
- Dr Vikram Gupta attended the International symposium (CAP-RES-22) on "Disaster Resilience and Green Growth for Sustainable Development" at National Institute of Disaster Management (NIDM), New Delhi during September 26-27, 2019.
- Dr Manish Mehta attended the 23rd RCC meeting of the Western Himalaya Regional Centre of NIH, Jammu on October 11, 2019.
- Dr Vinit Kumar attended - India International Science Festival at Kolkata, October, 2019.
- Dr Vikram Gupta attended the NIAS- DST training program on "Policy for Science and Science for Policy" in NIAS, Bangaluru during October 21-25, 2019.

- Dr Sushil Kumar attended the National Conference on "Promoting the Advancement of applied Sciences" at Department of Mathematics, HNB Garhwal University Campus, Badshahi Thaul, Tehri Garhwal (Uttarakhand) during October 22-23, 2019.
- Dr Santosh K. Rai attended the workshop/meeting on "The Conservation of water resources in Uttarakhand" at Uttarakhand Jal Sansthan Dehradun on October 25, 2019.
- Dr Vikram Gupta attended the satellite seminar on "Western Ghat and Dam Management" at National Center for Earth System Sciences (NCESS), Thiruvananthapuram, Kerala on November 21, 2019.
- Dr Kapesa Lokho attended MAESA Second International conference on "Applied Earth Sciences in Myanmar and Neighbouring Regions" during November 29 to December 1, 2019 and presented a paper entitled "Fossils from the easternmost part of the Indian Plate, Indo-Myanmar Range: implications on tectonic setting".
- Drs Anil Kumar and Pinky Bisht attended the workshop on "Luminescence Dating: Methodology and Applications" at NGRI, Hyderabad during December 7-11, 2019.
- Dr Rajesh Sharma delivered the Annual Day talk on "Geoscience for the Society' at Regional Office NABARD, Dehradun on December 10, 2019.
- Dr Vikram Gupta attended the 39th INCA International Congress "New Age Cartography and Geospatial Technology for Digital India" at Survey of India, Dehradun during December 18-20, 2019.
- Dr Kalachand Sain attended the National conference on "Innovation and Entrepreneurship & Startup Summit 2020" at IIT Delhi on January 2, 2020.
- Dr A.K. Singh attended the International conference on "Ophiolite and Oceanic Lithosphere" held at Muscat, Oman during January 12-14, 2020 and presented a paper entitled "Age and tectonic implications of Ophiolite in the Indo-Myanmar Orogenic Belt, northeast India".
- Dr Sushil Kumar attended the 4th National conference & workshop "CRUST20" of AAPG Foundation, at UPES, Dehradun during January 30 to February 1, 2020.
- Dr. Devajit Hazarika attended a meeting on "Integration of seismic instruments installed in India" held at National Disaster Management Authority (NDMA) Bhawan, New Delhi on February 05, 2020.
- Dr Jayangonda Perumal attended the 7th PAMC meeting held at IIT Roorkee to defend the Project Completion report of Quaternary Landform evolution funded by MoES, New Delhi during February 21-22, 2020.
- Dr Jayangonda Perumal attended a field trip to visit the trenches dug up under "Active Fault Mapping programme" in and around Ramnagar organized by PAMC of Seismology, MoES, New Delhi on February 23, 2020.
- Dr Jayangonda Perumal conducted Pre-Conference field workshop in collaboration with IIT-Kanpur for the "36th IGC participants in the Kumaun Himalaya" during February 25-29, 2020.
- Dr P.S. Negi attended the 14th Uttarakhanad State Science and Technology Congress, Uttarakhnad State Council for Science and Technology, UCOST Campus, Vigyan Dham, Dehradun, India during February 27-29, 2020 and presented a paper entitled "Real-time measurement of black carbon aerosols over high-altitude locations in Uttarakhand Himalayas".
- Dr M. Prakasam attended one-day workshop on "Total Organic Carbon Analysis of Solid and Liquid Samples (TOC-2020)" at VIT Chennai on February 28, 2020.

INVITED LECTURES DELIVERED BY INSTITUTE SCIENTISTS

- Dr Naresh Kumar delivered an Invited talk on "Quantification of seismic regimes of the Himachal Himalaya" in "National Workshop on Disaster management to mark 1905 Kangra earthquae" at Dharamshala Himachal Pradesh during April 3-4, 2019.
- Dr Rajesh Sharma delivered Key Note talk on "Industrial Minerals in Himalaya" in 3rd NGRSM, 2019 at WIHG, Dehradun on June 6, 2019.Dr
- Pradeep Srivastava delivered an invited talk on "Extreme Events and Holocene Floods: records from Garhwal Himalaya", NASI-UCOST workshop organized by UCOST Dehradun on June 11, 2019.
- Dr Vikram Gupta delivered an invited talk on "An overview of landslide hazards in the Himalaya" in NGU Trondheim, Norway on June 12, 2019.
- Dr Manish Mehta delivered an invited talk on "Melting of glacier in Himalaya due to climate change" at the Forest Survey of India, Dehradun on June 22, 2020.
- Dr Pradeep Srivastava delivered an invited talk on "Late Pleistocene-Holocene flood and human (?) imprints in Ladakh" in the workshop on "An Integrative Platform for Research on the Reconstruction of the Past in India, organized by University of Chicago and Birbal Sahni Institute of Palaeosciences at Leh on July 9, 2019.
- Dr Pradeep Srivastava, invited speaker "Neotectonic Evolution of Himalaya", Association of Petroleum Geologist Lecture series, ONGC Dehradun on August 31, 2019.
- Dr Kalachand Sain delivered a talk on "Near Surface Shallow Seismic Techniques Applications under the Indian Government program of Skills India development scheme at CSIR-NGRI, Hyderabad on September 16, 2019.
- Dr. Kalachand Sain delivered an invited talk to ICSTI-DST-NISCAIR conference on Digital Economy: The Space for Science and Technology Information & deliver a talk at NASC Complex, Pusa, New Delhi on September 19, 2019.
- Dr Sushil Kumar delivered an invited talk on "Chanderyan 2 Tatha Chandercump" in Hindi Pakhawara 2019 at WIHG on September 20, 2019.
- Dr Chhavi P. Pandey delivered an invited talk on "Brahamand ki Sair" in Hindi Pakhawara 2019 at WIHG on September 20, 2019.
- Dr Kalachand Sain was invited as Chief Guest at the National Conference on Earthquake: Investigation and Instrumentation & deliver a talk to be held at CSIR-CSIO Chandigarh during September 23-24, 2019.
- Dr Sushil Kumar delivered invited talk on "WIHG Seismic Network and Geophysical instrumentation: to understand the convergence tectonics, sub-surface structures and associated seismic hazard" in the National conference on "Earthquake: Investigation and Instrumentation" organized by the CSIR-Central Scientific Instruments Organization, Chandigarh in CSIR-CSIO Auditorium during September 23-24, 2019.
- Dr Kalachand Sain delivered a talk at CSIR Foundation Day' celebration at IIP, Dehradun on September 26, 2019.
- Dr Vikram Gupta delivered an invited talk on "An overview of landslides vis-à-vis climate change in the Himalaya" National Institute of Disaster Management (NIDM), New Delhi on September 27, 2019.
- Dr Sushil Kumar delivered an invited talk on "Understanding of Seismic Hazard Potential in the Northwest Himalaya, India" in the National Conference on 'Promoting the Advancement of applied Sciences' organised by Department of Mathematics, HNB Garhwal University Campus, Badshahi Thaul, Tehri Garhwal (Uttarakhand) during October 22-23, 2019.
- Dr Rajesh Sharma delivered invited talk on "Applictions of Raman Spectroscopy in Geoscience Research" at Sikkim University on November 13, 2019.
- Dr Pradeep Srivastava, invited, Geology of extreme hydrological events in Himalaya, Birbal Sahni Institue of Palaeosciences, Lucknow on November 18, 2019.

- Dr Vikram Gupta delivered an invited talk on "Landslide-scenarios in the Himalaya"in National Center for Earth System Sciences (NCESS), Thiruvananthapuram, Kerala on November 21, 2019.
- Dr Pradeep Srivastava, delivered an invited talk "Neotectonic Evolution of Himalaya" in Luminescence Dating Workshop at National Geophysical Research Institute, Hyderabad on December 8, 2019.
- Dr Kalachand Sain attended a Panel discussion and delivered an invited talk on New India -Science and Technology towards Scientific Social Responsibility", focusing mainly on the Draft National Policy at B.M. Birla Science Centre, Hyderabad on January 29, 2020.
- Dr Chhavi P. Pandey delivered an invited lecture on "Air Pollution and Climate Disruption in Earth's System" during "Inspire Internship Camp" sponsored by Department of Science and Technology (DST), Govt. of India, organized by HNB Garhwal University, Srinagar, Uttarakhand, India on January 29, 2020.
- Dr Sushil Kumar delivered a special invited talk on "Potential of Earthquakes Hazards in the Uttarakhand" in the 4th National conference & Workshop 'CRUST20' of AAPG foundation at UPES, Dehradun during January 30 to February 1, 2020.
- Dr Kalachand Sain delivered an invited talk on 4th Anniversary Celebration of Regional Science Centre, UCOST, Dehradun on February 3, 2020.
- Dr Kalachand Sain delivered an invited talk in the International Oil & Gas Conference & Exhibition (OGCE) at Scope Complex, Lodi Road, New Delhi on February 6, 2020.
- Dr Kalachand Sain attended and delivered an invited talk at SPG - Biennial International Conference & Exposition-2020" held at Kochi during 23-25 February, 2020 on February 23, 2020.
- Dr Kalachand Sain delivered an invited talk on "Energy Scenario in India at the Department of Marine Geology and Geophysics" in Cochin University on February 25, 2020.
- Dr Kalachand Sain delivered an invited talk at National Science Day function as Chief Guest at CSIR-Central Building Research Institute, Roorkee on March 2, 2020.

MEMBERSHIPS

Dr Sushil Kumar	• Member - Seismological Society of America (SSA)
Dr Sushil Kumar	• Member - Asia Oceania Geosciences Society (AOGS)
Dr Sushil Kumar	• Member - American Geophysical Union (AGU)
Dr Santosh Rai	• Member - Geochemical Society, America (ID 168259).
Dr Vikram Gupta	• Member - High Power Committee constituted by the Supreme Court of India to look after the various aspects of the Char Dham Pariyojana
Dr Pradeep Srivastava	• Member - Association of Petroleum Geologists
Dr Pradeep Srivastava	• Member - Association of Quaternary Researchers

POPULAR LECTURES DELIVERED IN THE INSTITUTE

National Science Day

The National Science Day week was celebrated by the institute by organizing the Science Quiz and Hindi Essay competitions for school children from 24th to 28th February 2020. Besides this, Hindi and English slogan competition was held in which scientist, staff and research scholars participated. To encourage the participation, the winners were awarded with citation and token prizes. The focal theme for this year's National Science Day was "Women in Science".

An open day was also observed on this day and museum and all laboratories of the institute were kept open for students and general public. In total nearly 45 educational institutions with more than 2000 school children and a large number of general public visited the museum and various laboratories. This year a special life size model of extinct giraffe of fiber was prepared. Which became a point of attraction to the students and general public.

On this day an invited special science lecture was delivered by Prof. Harsh K. Gupta President, Geological Society of India on "Developing Earthquake and Tsunami Resilient Society". A large number of students and general public attended the lecture. The occasion was marked by distribution of prizes by the chief guest to the winners who stood first, second and third in Science Quiz and Hindi Essay competitions. In science quiz RIMC and Welham's Schools jointly won the first prize and in Hindi Essay competition Bhagirathi International School won first prize. Shri Akhilesh Gairola won the first prize in Hindi and English slogan competitions.

PUBLICATION AND DOCUMENTATION

The Publication & Documentation section during the year brought out the (i) 'Himalayan Geology' volumes 40(2), and 41(1) (ii) Annual Report' of the Institute for the year 2018-19 in Hindi and English (iii) Hindi magazine 'Ashmika' volume 25 and (iv) Abstract volume (electronic) of 3rd National Geo Research Scholars Meet-2019 (June 6-8, 2019).

The section provides the facility & technical support services of printing and scanning to the scientists, research scholars and other staff of the Institute. Section was also involved in dissemination of the publications to individuals, institutions, life time subscribers, book agencies, national libraries, indexing agencies, under exchange program and maintaining the sale & accounts of publications. Apart from this, works pertaining to printing of brochures and certificates etc., are also taken-up.

Himalayan Geology (journal) website http://www.himgeology.com is functioning with online enquiry, online prepaid subscription order, and online manuscript submission facility under this section. All information regarding the journal including contents and abstracts is up-dated time to time on the website. Online access of current volume to the Life Time Subscribers (those have given the choice to obtain the volumes in soft copy through online access/email) also has been provided. Journal is indexed in Thomson Reutors (US), Elsevier (Netherlands), and in Indian Citation Index (India). Four new members got registered under the Life Time Subscriber Scheme (LTSS) Membership for Himalayan Geology journal bring the total registered number to 485.

LIBRARY

The Library of Wadia Institute of Himalayan Geology has a special status owing to its best collection of books, monographs, journals, and e-books etc. on the mountain building process, geological and geophysical phenomenon with special reference to Himalaya. Also the collection and services offered makes it one of the best libraries in the country in the field of earth sciences. The scientists, researchers, projects staff and students make full utilisation of the Library while publishing their research work in the reputed peer-reviewed journals. Specialists and professionals across the country also visit our Library to consult thematic and rare collections available at the Library. The Library has more than 4000 selected e-books from different publishers and learned societies on the thrust areas of the research in the Institute.

Institutional Repository (IR): For the easy access and exclusive publications of the research work by WIHG, further digitization of research publications have been carried out by incorporating them into the Institutional Repository (IR). The IR is essentially developed using DSpace (OSS) for organizing and disseminating the research output of the Institute. The articles published by our scientists in various journals have also been digitised. The repository consists of 100 full PDF text of Prof D.N. Wadia's publications and 2058 PDFs of WIHG Scientist's publications and placed on the intranet within the Institute.

Acquisition of Documents: The Library has paid and subscribed to 65 International and 38 Indian Journals. 08 more reference books are added and 15 books are received as gratis.

National Knowledge Resource Consortium (NKRC): The Library is a member of NKRC and continue to receive the support of Consortia towards online access to Elsevier's "Earth and Planetary Science collection", Wiley's "Earth, Space & Environmental Sciences"; Springer "Earth and Environmental Science and Chemistry" collections. In addition to this, WIHG Library has access to the publications of American Institute of Physics, American Physical Society, Derwent Innovation Index (with Web of Knowledge), Emerald Group Publishing, IEEE, NPG: Nature -Main Journal, NPG: Nature Geoscience, Royal Society of Chemistry, Science magazine, Springer Journals, Taylor & Francis, Web of Science, Wiley & Blackwell. All these publishers contribute online access to more than four hundred journals' titles, apart from our own subscription.

Binding of Journals: The binding work of loose issues of journals was undertaken by the Library. A total number of 185 volumes of journals also are bound during 2019-20. All the volumes have been accessioned and their bibliographic data entry and has been incorporated into the digital database.

Inter-Library Loan: The WIHG scientists were provided books/journals on inter-library loan from the Libraries of other organisations situated at Dehra Dun as per the requirement of the users.

Reprography facility: The Library serves as central facility for the reprography demand of the Institute. This facility is being extended to scientific and administrative sections of the Institute. The facility was also extended on payment basis to the external users of the Library and a total of 70000 pages were copied during the year.

Computer Facility: The Library has the hub of computers for the users for accessing the e-books and e-journals and other e-resources available, either subscribed by WIHG Library or available through NKRC. This facility was also extended to the students and summer trainees. The hub is also being used for conducting several tests towards the recruitment of administrative and technical staff of the Institute.

S.P. NAUTIYAL MUSEUM

Museum of the Institute remained the main attraction for visitors from different walks of life, including a large number of students from different part of country. The exhibits and the information provided in the Museum continued to attract the students and general public not only from the remote corners of India but also from abroad. Some of the educative exhibits include Drifting Continents, Interior of Earth, Geological clock, Glaciers, Origin and Evolution of life etc. The rock, mineral and fossil specimens from the different geological horizons of Himalaya are displayed in the Museum, and these specimens are much appreciated by the young students. This year too, students in large groups from different educational institutions, universities, and colleges and from other institutions visited the museum and got benefited from the deliberation given by the experts guiding them. The Institute received visitors from USA, Bangladesh, Norway, Japan and other countries. As part of their educational program, IFS probationers, ITBP personals, Forest Rangers, Navy Officers, Teacher Trainees etc. also visited the Museum. Museum also propagates its activities to general public and the students through its educational brochures. The Museum also helped the local students in completing their school projects on earthquakes, rock and minerals, origin of life etc.

The Museum observed open days on National Science Day, Foundation Day, Founders Day and Technology Day. Like the previous year's enormous number of students and general public visited the museum on these occasions. The print media gave a wide coverage of the various functions organized during these open days. Science Quiz and Essay competitions were organized during the Science week celebration. Students of various schools of Doon valley participated in the competition.

This year, Institute participated in an outdoor exhibition from 5th to 8th November 2019 at Kolkata which was organized under the banner of India International Science festival. Another one-day exhibition was arranged on 10th February 2020 at Uttarakhand Space Application Centre. Both the exhibitions received an enormous response from mass gathering of the students and general public in the event.

An important addition to Museum exhibits is a wall clock (24" diameter) having geological time scale on its dial. A smaller version of it (12" dia) was also got prepared from the market in bulk for commercial purpose and as memento.

TECHNICAL SERVICES

Analytical Services

The number of samples analyzed by various instruments listed in the following table

Laboratory/Instruments	Number of samples analysed		
	WIHG Users	Outside Users	Total
ICP-MS Lab	423	396	819
LA MC ICPMS	Liquid mode: 465 Solid mode:14 (~750 U-Pb spot ages) Including standards	Solid mode:14 (~700 U-Pb spot Ages)	Liquid mode: 465 Solid mode: 28 (~1450 U-Pb spot ages) Including standards
Stable Isotope Lab	2947	233	3180
Luminescence Dating (TL/OSL) Lab	95	31	126
Fission Track Lab & Mineral Separation Lab (includes samples for Fission Track Analysis and Zircon U-Pb Geochronology)	Mineral Separation: 114 Fission Track Counting: 20	Mineral Separation: 07	Mineral Separation: 121 Fission Track Counting: 20
XRF Lab	257	285	542
SEM Lab	99	139	238
Rock magnetic & Paleomagnetism Lab	431	Nil	431
Dendrochronology Lab	120 Tree core samples	Nil	120 Tree core samples
Micropaleontology Lab	195	10	205
Laser Particle Size Analyzer (LPSA) Sedimentology Lab Vibratory Sieve Shaker	338	--	338
Geotechnical Lab			
Palyonology Lab	38	43	81
Total Organic Carbon (TOC) Lab	376 (5 users)	Nil	376

Photography Section

The Photography section provides high-quality images of various functions and activities organized by the institute. These high-quality digital images of important events are useful for the institute web pages as well for preparation different reports by the institute. During the reporting year 2019-2020, approximately 4000 photographs were taken using high-resolution SLR digital cameras to cover the various functions organized in the Institute including Foundation Day, Founders Day, National Science Day, National Technology Day, New Year's Day, Republic Day, Independence Day, Seminars/Symposia, cultural program, and superannuation parties for Institute staff, etc. In addition to the photography of institute events, 700 snaps were taken for rocks and fossils. The colour printing of around 300 digital images was arranged from the market. The majority of scientists have cameras issued permanently to them for use in the field and laboratory, while the remaining scientists from projects and research scholars are provided cameras from a pool as and when they require it.

Drawing Section

The Drawing Section provides services towards cartographic needs of the scientists of the Institute for their institute as well as sponsored projects works. During the year, the section has provided 35 geological maps/structural maps/geomorphological maps/ seismicity diagrams for the scientists and research scholars of the Institute. Besides, the tracing of fourteen topographic sheets/aerial photo maps was carried out along with the preparation of the two geological columns. The section has also provided name labels, thematic captions during different activities and functions of the Institute including writing work on the photo identity cards of the employees of the Institute.

Sample Preparation Laboratory

The sample preparation laboratory provided thin/ microprobe/polished sections to the requirements of the Institute Scientists and Research Scholars. During 2019-2020, the laboratory provided more than 1280 thin and polished sections to various users for carrying out microscopic, fluid inclusion studies. The laboratory also processed crushing/grinding of more than 1260 rock samples for carrying out major, trace, and REE analysis by ICPMS, and XRF methods.

Computer and Networking Section

The objective and purpose of the WIHG Computer Section are to take care of all the computational requirements of the Institute to facilitate research work free of any IT related worries. For the purpose, the Computer and Networking section is managing and hosting various servers like web server, DNS, FTP, Email, Storage, and Application server on of its own and providing email, internet, and storage services hassle-free and with 100 % uptime to institute employees. All the servers are being managed on a secure Linux environment and most of the time utilizing the latest open source technologies. Presently Institute is connected with the high-speed National Knowledge Network (1 Gbps) link. However, for uninterrupted internet connectivity, a standby internet bandwidth leased line connectivity (over radio link) has also been taken. The section is maintaining a virus and spyware-free environment by adopting not only centralized anti-virus and anti-spyware solution but also implementing the prevailing preventive security measures in this regard. The most important and unique implementation of the computer section is the extensive use of open-source software on different computers, workstations, and servers. This has been best implemented in realizing the virtualization of resources for optimum use of available hardware resources. This has helped in saving considerable financial requirements that may have been spent in purchasing their commercial counterpart, in order to provide the existing services and support.

Beside this Computer and Networking section :-

- Caters to the hardware troubleshooting and maintenance requirements of the whole Institute through maintaining and monitoring the AMC contract in this regard. Along with hardware troubleshooting, support is also being provided for different software used in the Institute and also for other facilities like data backup, data retrieval, etc.
- Uses the latest and state of art networking technologies for excellent speed and reliability of all the network-related services.
- Maintains and upgrade the network as per the requirement. The network is not limited to the office but the same has been extended to the WIHG residential colony and the Institute Guest House also.
- Provides VPN facility to facilitate the access of Institute resources securely over the public network.
- Provides technical support services to the different laboratories, projects, and also during the various conferences, seminars, and other events that are held in the Institute from time to time.
- Maintains and hosts different web portals of the Institute viz., Institute website, Institute publication portal, WAICS (Wadia Analytical Laboratory Instrument Facility and Consultancy Advisory Services) portal.

CELEBRATIONS

5th International Yoga Day

5th International Yoga Day on 21, June 2019 was celebrated in the Institute. On this occasion, more than 100 scientist, employees and research student participated for Yoga 6:30 AM to 7:30 AM under the directive and guidance of Yoga Instructors.

Foundation Day

The Institute was celebrated its 51st Foundation Day on Saturday, June 29, 2019. Dr. M. Rajeevan, Secretary to the Government of India, Ministry of Earth Sciences was the Guestof-Honour and Dr. Kalachand Sain chaired the function. The Foundation Day Lecture was delivered by Dr. M. Rajeevan, (Secretary to the Government of India, Ministry of Earth Sciences) on "Observed climate change and its future projection". On this Occasion was also marked by distribution of awards by chief guest R.C. Mishra gold medal and best paper published by the institute scientist. Prof. R.C. Mishra Memorial Gold Medal was jointly awarded to "Dr. Priyadarshi Chinmoy Kumar" WIHG and Dr. Siddharth Prizomwala, ISR, Gujarat. The "Best Paper Award" was given to Mr. Purbajyoti Phukon for their joint paper on "Characterizing anatexis in the Greater Himalayan Sequence (Kumaun, NW India) in terms of pressure, temperature, time and deformation' Published in Lithos (Elsevier Publication).

Chief Guest Dr. M. Rajeevan, delivering the Foundation Day lecture (Top). Dr. Siddharth Prizomwala, ISR, Gujarat (right) and Dr. Priyadarshi Chinmoy Kumar" WIHG (left) received, Prof. R.C. Mishra Memorial Gold Medal (Bottom).

Independence Day

Institute celebrated 73rd Independence Day on August 15, 2019. On this occasion, flag hoisting was followed by a formal address by Dr. Kalachand Sain, director of the institute. As a mark of Independence Day celebration various programmers were organized such as tree plantation, drawing competition and game for institute employees and their children. Prizes were distributed to the winner of various events.

Independence Day Celebration in the Institute

Swachchata Pakhwara

Institute observed Swachchata Pakhwara during 20 september to 2 october, 2019. Under this programme the voluntary cleaning of institute campus, part of GMS road and adjacent area, Wadia colony, Laboratories, and office room of the institute were carried out.

Swachhta Pakhwada and cleaning drive in the campus and GMS Road

Founder's Day

The Institute was celebrated the 136th birth anniversary of Prof. D.N. Wadia on 23rd October 2019 as 'Founder's Day. This year the Institute was celebrated the birth anniversary of Prof. D.N. Wadia by paying floral tribute to the legend.

Vigilance Week

The institute observed Vigilance Week during October 28 to November 02, 2019 with the Theme of on the theme “Integrity-A way of life”. Towards this scientist and other staff of the institute took pledge on 29th October 2019.

Republic Day

The Institute was celebrated the 71st Republic Day on 26 January 2020, on this occasion, flag hoisting was followed by a formal address by Dr. Kalachand Sain, director of the institute. As a mark of Republic Day celebration various sports and cultural activities were organized in the institute for the employees and their children. Prize were distributed to the winner of various events.

Republic day celebration in the institute

Science week

Science week has been observed in the institute during February, 24 - 28th Feb. 2020 as a part of the National Science Day celebration. Various activities were organized for school children and for the employees of the Institute. Various educational Institutions of Dehradun were invited for participation in the Science Quiz and Hindi Essay Competitions. Moreover, Hindi and English slogan competition was also held in in which scientists, staff and research scholars participated. To encourage the participation, the winners were awarded with the certificate and token cash prizes.

Prof. Harsh K. Gupta, President, Geological Society of India was the chief guest for the National Science Day 28th February 2020 and he delivered the 'National Science Day lecture' on 'Developing Earthquake and Tsunami Resilient Society'. The lecture was attended by large number of students of different schools, general visitors and by the institute staff. The occasion was also marked by distribution of prizes by the chief guest to the winner of the Science Quiz and Hindi essay competitions.

Institute celebrated National Science Day, Prof. Harsh K. Gupta was the chief guest for the National Science Day (Top). Students and teachers visited various lab and the Museum

National Women's Day

Institute celebrate 'International Women's Day' on March 8, 2020. All the female employees and research scholars gathered to share their experiences in life and celebrate the event with enthusiasm.

Outreach Program

Our institute has taken an initiative to reach to common people for disaster mitigation from earthquakes under a project entitled "भूकंप के लिए तैयारी करने और खतरे की कमी के लिए शिक्षा और जागरूकता कार्यक्रम: ("Education and awareness program for earthquake preparedness and hazard mitigation") The objectives of this program are i) Awareness program for common people ii)Installation of a seismograph in local schools for the data recording and demonstration of real earthquake data iii)Educating people and school students for earthquake hazard mitigation iv) earthquake mockdrill.

In 2019-20, Various schools and villages in different part of Uttarakhand state covering almost 2200 students/villagers were educated through interaction. Earthquake related lectures have been delivered to make aware about the safety and preventing measures to be taken during the earthquake. The earthquake recording system was demonstrated to the common people. In order to achieve this objective, real time recording of seismograph was exhibited to show them the recording of earthquake phenomenon and educating them about its utilization. The mock drill exercise was demonstrated through power point presentation and videos. The actual mock drill exercises were performed by the students in various schools/colleges/institutes. The earthquake mock drill exercise explored all possibilities to make the disaster management exercise effective. The response forms were filled by the students indicating which type of difficulties they have faced during the mock drill, these feedback forms proved to be a great tool for the improvement of this program. Distribution and explanation of pamphlets contents are made through this awareness program.

Under this program, three school seismograph system have been installed at three different schools. Few teachers and students have been trained so that they

Lecture and Interaction with the Students and schools staff

Mock Drill

Installation of the school seismographs at different schools

can see the real wave form data of their own. They are trained about functioning of instrument and handling of earthquake data. Apart from the school, where instrument is installed, students from the nearby school are also invited for the demonstration of seismograph. This instils the confidence to prepare and mitigate the loss of life and property.

Under this program following schools and nearby Villages were visited during 2019-2020

1. Chakrata Inter college, Langha Pokhri Village 07/05/2019
2. Tapovan Vidyalaya, Nalapani, Dehradun 15/06/2019
3. Cantt. Chakrata Inter college, Chakrata 10/07/2019
4. Graphic Era Hill University, Clementown, Dehradun 06/08/2019
5. JNV Shankarpur, Sahaspur, Dehradun 08/08/2019
6. Wildlife Institute, Dehradun 09/08/2019
7. Wadia Institute of Himalayan Geology, Dehradun (Hindi Pakhwada) 18/09/2019
8. Cant Chakrata Inter college, Chakrata 15/11/2019
9. Wadia Institute of Himalayan Geology, Dehradun 06/12/2019
10. Shamford Doon School, Dehradun 29/01/2020
11. EkLavaya Adarsh Vidyalaya, Kalsi 13/02/2020

DISTINGUISHED VISITORS TO THE INSTITUTE

- Dr. M. Rajeevan, Secretary to the Govt. of India, Ministry of Earth Sciences, delivered foundation Day lecture on 29th June 2019.
- Dr Anjan Ray, Director, Indian Institute of Petroleum, delivered Founder's Day lecture "Combating climate change with Domestic Carbon Resources in the Himalaya" on 23rd October 2019.
- Dr Kristin Morell, faculty, Department of Earth Sciences, University of California, Santa Barbara delivered a talk on "Active strain accumulation and Seismotectonics in the hinterland of the northwest Himalaya" on 18th October 2019.
- Shri Pradipta Mishra, Executive Director- Head of the Institute, GEOPIC, ONGC Dehradun, delivered a talk on "Hydrocarbon Exploration - New Frontiers & Challenges" on 2nd January, 2020.
- Dr Maanasa Raghvan, Department of Human Genetics, University of Chicago delivered a talk on The Paleogenomics Revolution and our Molecular Past" on 6th February 2020.
- Prof. Harsh K. Gupta, President, Geological Society of India delivered National Science Day Lecture "Developing Earthquake and Tsunami Resilient Society" on 28th February, 2020.

STATUS OF IMPLEMENTATION OF HINDI

WIHG, Dehradun is not only committed toward the increasing use of Hindi in day to day office work but also in research work to the possible extent. The Institute follows the policy and guidelines of Rajbhasha VIbhag and regularly submitting its quarterly and half yearly progress report to Rajbahsah Vibhag, Department of Science and Technology as well as to NARAKAS, Dehradun. Implementation of Hindi in institute is being monitored by Rajbhasha Implementation Committed headed by Director, WIHG. The committee take note of implementation of Hindi in its quarterly meetings which are regularly organised.

This year under the banner of Rajbhasha Implementation committee of the Institute, Hindi Pakhwara is observed from 12 Sep to 26 September, 2019 in the institute. Various programs have been organised. The pakhwara is inaugurated by Padma Shri Leeladhar Jaguri, Hindi Poet/writer of International fame. In his opening remark, he described the evolution and travel of words in languages. He emphasised that the progress of words of any language at any time depend upon the acceptance and usage of society.

Dr Partibha Sharma, Psychologist, Doon Psychotherapeutic Centre, a name of repute in the field of Psychology especially for issues related to Child behaviour delivered an invited lecture on "Modern Lifestyle, Mental Stress and Cure". The topic of her lecture is germane and central to today's requirement of everyone. In her lecture, she elaborated the reasons of stress of every kind and then described how one can avoid it. She has answered questions and queries of the audience patiently and appreciate them also.

Second invited lecture was delivered by Prof Ravindra Singh Bisht, Head of the ENT Department, Doon Medical College Dehradun. In his lecture he described briefly about the structure of ear, problems and diseases of ear. He explained how and why one should take care of his ear. He answered number of queries from audience patiently and appreciate the awareness of audience in the subject.

Employees from the institute were also invited for delivering the talk on various topics in Hindi. Dr Kalachand Sain, Director WIHG taking the lead, delivered his lecture in hindi on "Gas Hydrates: Possible Solution for the need of Energy in India". In his lecture, Dr Sain explained what Gas hydrates is and how it is detected with active seismic method and what are the characteristics feature of signals in the area, where there is possibility of Gas Hydrates. Thereafter lecture on "Rocks and Rock Arts" by Dr. Rajesh Sharma, Scientist G, "Chandrayan-2 and Chandrakamp" by Dr. Sushil Kumar, Scientist F, "Hot water springs from NW indian Himalaya" by Dr Santosh Rai, Scientist E, "Brahmaand kee Sair" By Dr Chavi Pant Pandey, Scientist "C", and "Technology and Challenging and interesting facts" by Mr Tajender Ahuja aptly fulfiled the knowledge thirst of audience. In this series, Dr Gautam Rawat, Rajbhsaha Adhikari and Scientist D draw the attention of audience by giving lecture on "Hindi Typing in view of technology". In his lecture he explained the concept of Unicode and demonstrated the use of Inscript keyboard for writing in Indian Languages. Beside these lectures, number of other programs like essay competition, debate for school students, Hindi quiz for employees etc. were organised. The chief guest for closing ceremony of the Pakhwara was Col (Retd) Ajay Kothiyal, former Director, National Institute of Mountaineering, Uttarkashi. A cultural program was executed by the students of Sharp Memorial School, a school established in 1887 and dedicated to visually impaired students. Prizes for different competitions were distributed by the chief guest. In his remarks, Col Kothiyal praise the work of WIHG and shared his experiences of rebuilding KedarNath Pilgrimage area.

This year we published 25th issue Annual Hindi Magazine "Ashmika". Science articles in the magazine were contributed by authors serving in various organisations of India and by employees of the institute. The articles of the magazines are informative and well appreciated by the readers.

MISCELLANEOUS ITEMS

1. Reservation/Concessions for SC/ST employees

Government's orders on reservations for SC/ST/OBCs are followed in recruitment to posts in various categories.

2. Monitoring of personnel matters

Monitoring of personnel matters relating to employees of the Institute is done through various Committees appointed by the Director/Governing Body from time to time.

3. Mechanism for redressal of employee's grievances

The Grievance Redressal Committee (GRC), consists of five senior scientists/officers, is operational in this institute to look after the Redressal of employees' grievances. During the reporting period, a total of six grievances were received from a few regular employees, project employees and an ex-contract employee. Of these, four grievances were received through the Prime Minister's Office (PMO), New Delhi, and two grievances were received through the Department of Science and Technology (DST), New Delhi. Among the four grievances received through the PMO, one grievance is related to non-implementation of the 7th Central Pay Commission to few employees and three grievances were related to the issues faced by Centre for Glaciology (CFG) project employees. For solving these grievances, the GRC held numerous meetings and checked through various official documents and also interacted with the aggrieved employees. The committee found that the intervention from the DST and or finance ministry is required to resolve these issues and hence necessary follow up actions were taken. Through DST, an ex-contract employee of the institute has registered clarification related to the qualification and selection procedure of Group C and D employees and suitable reply was made available to him.

4. Welfare measures

The Institute has various welfare measures for the benefit of its employees. Various advances like House Building Advance, Conveyance Advance, Festival Advance, etc. are given to the employees. There is a salary Earner's Cooperative Society run by the Institute employees that provide loans to its members as and when required. The Institute also runs a canteen for the welfare of the employees. As a welfare measure, the Institute is providing recreational facilities to its employees.

5. Mechanism for redressal of complaints of sexual harassment of women employees at work places

To inquire into the complaints of sexual harassment of women employees at work places in the Institute, a separate Committee has been constituted. The Committee consists of seven members. The Chairman and three other members of the Committee are female officers, which includes a female officer from the Department of Food and Civil supplies, Govt. of Uttarakhand. No complaint of sexual harassment of women employees at work places was received by the Committee during the year 2019-20.

6. Status of Vigilance Cases

No vigilance case is pending in the year 2019-20

7. Information on the RTI cases

Four applications for seeking information under the Right to Information Act, 2005 were carried forward from the previous year 2018-19.

The details of information on the RTI cases during the year 2019-20 are as under:

Details	Opening balance as on 01.04.2019	Received during the year 2019-2020	Number of cases transferred to other public authorities	Decisions where requests/ appeals were rejected	Decisions where requests/ appeals accepted
1	2	3	4	5	6
Requests for information	11*	47	01	01	56
First appeals	1	08	0	0	09

* Eleven applications for seeking information under the RTI Act 2005 were carried forward from the previous year 2018-19. These were disposed off in the current year 2019-2020.

8. Sanctioned Staff strength (category wise)

Group/ Category	Scientific	Technical	Administrative	Ancillary	Total
A	63	0	2	0	65
B	0	4	14	0	18
C	0	63	22	40	125
Total	63	67	38	40	208

9. Sanctioned and released budget grant for the year 2019-2020

Plan : ₹ 3709.97 Lakhs

Non-Plan : -

Total : ₹ 3709.97 Lakhs

STAFF OF THE INSTITUTE

Scientific Staff

1	Dr. Kalachand Sain	Director
2	Dr. Meera Tiwari	Scientist 'G' (Retired on 30.04.2019)
3	Dr. Rajesh Sharma	Scientist 'G'
4	Dr. G. Philip	Scientist 'G' (Retired on 31.07.2019)
5	Dr. H.K. Sachan	Scientist 'G'
6	Dr. Sushil Kumar	Scientist 'F'
7	Dr. D.P. Dobhal	Scientist 'F'
8	Dr. Vikram Gupta	Scientist 'F'
9	Dr. Suresh N.	Scientist 'F'
10	Dr. Pradeep Srivastava	Scientist 'F'
11	Dr. Ajay Paul	Scientist 'E'
12	Dr. S.S. Bhakuni	Scientist 'E' (Retired on 30.06.2019)
13	Dr. R. Jayangondaperumal	Scientist 'E'
14	Dr. A.K. Singh	Scientist 'E'
15	Dr. Kapesa Lokho	Scientist 'E'
16	Dr. K. Luirei	Scientist 'E'
17	Dr. P.S. Negi	Scientist 'E'
18	Dr. A.K.L Asthana	Scientist 'E'
19	Dr R.K. Sehgal	Scientist 'E'
20	Dr. Jayendra Singh	Scientist 'E'
21	Dr. B.K. Mukherjee	Scientist 'E'
22	Dr. Santosh Kumar Rai	Scientist 'E'
23	Dr. Gautam Rawat	Scientist 'D'
24	Dr. Naresh Kumar	Scientist 'D'
25	Dr. Devajit Hazarika	Scientist 'D'
26	Dr. Dilip Kumar Yadav	Scientist 'D'
27	Dr. Kaushik Sen	Scientist 'D'
28	Dr. Satyajeet Singh Thakur	Scientist 'D'
29	Dr. Swapnamita Choudhuri	Scientist 'D'
30	Dr. Narendra Kumar Meena	Scientist 'D'
31	Dr. Param Kirti Rao Gautam	Scientist 'D'
32	Dr. Manish Mehta	Scientist 'D'
33	Dr. Aparna Shukla	Scientist 'D' (On Lien)
34	Dr. Rajesh S.	Scientist 'D'
35	Dr. Vikas	Scientist 'C'
36	Dr. Som Dutt	Scientist 'C'
37	Dr. Anil Kumar	Scientist 'C'
38	Sh. Saurabh Singhal	Scientist 'C'
39	Dr. Narendra Kumar	Scientist 'C'
40	Dr. Vinit Kumar	Scientist 'C'
41	Dr. Aditya Kharya	Scientist 'C'
42	Dr. Suman Lata Rawat	Scientist 'C'
43	Dr. Chhavi Pant Pandey	Scientist 'C'
44	Dr. Parveen Kumar	Scientist 'C'
45	Dr Sudipta Sarkar	Scientist 'B'
46	Dr. M. Prakasam	Scientist 'B'
47	Dr. Paramjeet Singh	Scientist 'B'
48	Dr. Aliba AO	Scientist 'B' (Resigned on 27.01.2020)
49	Dr. Sameer Kumar Tiwari	Scientist 'B'
50	Dr. Pinkey Bisht	Scientist 'B'
51	Dr. C. Perumalsamy	Scientist 'B'
52	Dr. Pratap Chandra Sethy	Scientist 'B'

Technical Staff

1	Shri Sanjeev Kumar Dabral	Sr. Technical Officer
2	Shri Chandra Shekhar	Sr. Technical Officer (Retired on 30.06.2019)
3	Shri Samay Singh	Sr. Technical Officer
4	Shri Rakesh Kumar	Sr. Technical Officer
5	Shri H.C. Pandey	Sr. Technical Officer
6	Shri N.K. Juyal	Sr. Technical Officer
7	Shri T.K. Ahuja	Technical Officer
8	Shri C.B. Sharma	Assistant Engineer
9	Shri Rambir Kaushik	Technical Officer
10	Shri S.S. Bhandari	Technical Officer
11	Shri Gyan Prakash	Asstt. Pub. & Doc. Officer
12	Shri Bharat Singh Rana	Librarian
13	Dr. Jitendra Bhatt	Jr. Technical Officer (Retired on 30.04.2019)
14	Dr. Pankaj Chauhan	Jr. Technical Officer
15	Shri Lokeshwar Vashistha	Sr. Lab.Technician
16	Dr. S.K. Chabak	Sr. Lab.Technician
17	Shri R.M. Sharma	Sr. Lab.Technician
18	Shri C.P. Dabral	Sr. Lab.Technician
19	Ms. Sarita	Sr. Technical Assistant
20	Shri Rakesh Kumar	Sr. Technical Assistant
21	Shri Rajendra Prakash	Sr. Lab. Assistant
22	Shri Nand Ram	Elect.cum-Pump.Optr.
23	Shri Balram Singh	Elect.cum-Pump.Optr. (Retired on 31.01.2020)
24	Ms. Sakshi Maurya	Technical Assistant
25	Ms. Disha Vishnoi	Technical Assistant
26	Shri Prateek Negi	Artist cum Modeller
27	Shri Rahul Lodh	Lab Assistant
28	Shri Nain Das	Lab Assistant
29	Shri Tarun Jain	Draftsman
30	Shri Pankaj Semwal	Draftsman

31	Shri Santu Das	Section Cutter
32	Shri Puneet Kumar	Section Cutter
33	Shri Hari Singh Chauhan	Field-cum-Lab-Attendant
34	Shri Ravi Lal	Field-cum-Lab-Attendant
35	Shri Preetam Singh	Field-cum-Lab-Attendant
36	Mrs. Rama Pant	Field Attendant
37	Shri R.S. Negi	Field Attendant (Retired on 31.08.2019)
38	Shri Ramesh Chandra	Field Attendant
39	Shri B.B. Panthri	Field Attendant
40	Shri M.S.Rawat	Field Attendant
41	Shri Sanjeev Kumar	Field-cum-Lab-Attendant
42	Shri Deepak Tiwari	Field-cum-Lab-Attendant
43	Shri Ajay Kumar Upadhaya	Field-cum-Lab-Attendant
44	Ms. Sangeeta Bora	Field-cum-Lab-Attendant
45	Sh. Deepak Kumar	Field-cum-Lab-Attendant
46	Ms. Anjali	Field-cum-Lab-Attendant

Administrative Staff

1	Shri Pankaj Kumar	Registrar
2	Shri A.S.Negi	Administrative Officer (Died on 14.04.2019)
3	Mrs. Manju Pant	Asstt. Fin. & Accounts Officer
4	Shri Manas Kumar Biswas	Store & Purchase Officer
5	Shri M.C.Sharma	Office Superintendent (Retired on 31.07.2019)
6	Shri S.K.Chhettri	Accountant
7	Smt. Rajvinder Kaur Nagpal	Stenographer, Grade - II
8	Shri Rahul Sharma	Assistant
9	Shri S.K.Srivastava	Assistant
10	Shri R.C.Arya	Assistant (Retired on 31.07.2019)
11	Mrs. Prabha Kharbanda	Assistant
12	Mrs. Kalpana Chandel	Assistant
13	Mrs. Anita Chaudhary	Assistant
14	Ms. Shalini Negi	Stenographer, Grade - II
15	Ms. Richa Kukreja	Stenographer, Grade - III
16	Shri Shiv Singh Negi	Upper Division Clerk
17	Mrs. Neelam Chabak	Upper Division Clerk
18	Mrs. Seema Juyal	Upper Division Clerk
19	Mrs. Suman Nanda	Upper Division Clerk
20	Shri Kulwant Singh Manral	Upper Division Clerk
21	Shri Vijai Ram Bhatt	Upper Division Clerk
22	Shri Girish Chander Singh	Upper Division Clerk
23	Shri Rajeev Yadav	Lower Division Clerk
24	Shri Deepak Jakhmola	Lower Division Clerk
25	Shri Dinesh Kumar Singh	Lower Division Clerk
26	Ms. Rachna	Lower Division Clerk

Ancillary Staff

1	Mrs. Kamla Devi	Bearer
2	Mrs. Deveshawari Rawat	Bearer
3	Shri S.K. Gupta	Bearer
4	Mrs. Omwati	Bearer
5	Shri Jeevan Lal	Bearer
6	Shri Surendra Singh	Bearer
7	Shri Pritam	Bearer
8	Shri Ramesh Chand Rana	M.T.S.
9	Shri Pankaj Kumar	M.T.S.
10	Shri Ashish Rana	M.T.S.
11	Shri Harish Kumar Verma	M.T.S.
12	Shri Dinesh Parsad Saklani	Guest House Attendant cum Cook
13	Shri Sunil Kumar	Guest House Attendant cum Cook
14	Shri Rohlu Ram	Chowkidar
15	Shri H.S. Manral	Chowkidar
16	Shri G.D. Sharma	Chowkidar
17	Shri Satya Narayan	Mali
18	Shri Hari Kishan	Safaiwala (Retired on 31.12.2019)

Contractual Staff

1	Shri Dhanveer Singh Shah	Lower Division Clerk
3	Smt. Megha Sharma	Lower Division Clerk
3	Shri Rezaw Uddin Chaudhary	Driver
4	Shri Rajesh Yadav	Driver
5	Shri Bhupendra Kumar	Driver
6	Shri Manmohan	Driver
7	Shri Vijay Singh	Driver
8	Shri Rudra Chettri	Bearer
9	Shri Laxman Singh Bhandari	Chowkidar
10	Shri Pradeep Kumar	Chowkidar
11	Shri Kalidas	Chowkidar

MEMBERS OF THE GOVERNING BODY/RESEARCH ADVISORY COMMITTEE /FINANCE COMMITTEE / BUILDING COMMITTEE

Governing Body
(w.e.f. Nov. 13, 2018)

Sl.	Name	Address	Status
1.	Prof. Ashok Sahni	Emeritus Professor, Lucknow University 98, Mahatma Gandhi Marg, Lucknow -226001,UP (India)	Chairman
2.	Secretary to the Government of India or his/her nominee	Dept. of Science & Technology, Technology Bhawan, New Mehrauli Road, New Delhi - 110016 (India)	Member
3.	Prof. Talat Ahmad	Vice Chancellor, Jamia Millia Islamia Jamia Nagar, New Delhi-110025 (India)	Member
4.	Dr V.M. Tiwari	Director, CSIR-NGRI (Council of Scientific & Industrial Research) Uppal Road, Hyderabad-500007,Telangana (India)	Member
5.	Prof. Harilal B. Menon	Department of Marine Sciences Goa University,Taleigoa Plateau Goa-403206 (India)	Member
6.	Prof. G.V.R. Prasad	Department of Geology, Center for Advance Studies University of Delhi, Delhi-110007 (India)	Member
7.	Dr. Rasik Ravindra	Former Director, National Center for Antarctic and Ocean Research (NCAOR) Headland Sada,Vasco-da-Gama-403804,Goa (India)	Member
8.	Prof. Deepak Srivastava	Head, Department of Earth Sciences Indian Institute of Technology Roorkee (IITR), Roorkee-247667, Uttrakhand (India)	Member
9.	Prof. Pramod K. Verma	Department of Applied Geology Vikram University, University Road, Madhav Bhavan (Near Vikram Vatik), Ujjain-456010, MP (India)	Member
10.	Prof. S.K. Dubey	Former Director, Indian Institute of Technology Khargapur	Member
11.	Financial Adviser or his/her nominee	Dept. of Science & Technology, Technology Bhawan, New Mehrauli Road, New Delhi-110016 (India)	Member
12.	Director, WIHG	Director, Wadia Institute of Himalayan Geology, 33, GMS Road, Dehra Dun-248001, Uttrakhand (India)	Member Secretary
13.	Sh. Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, 33, GMS Road, Dehradun-248001, Uttarakhand (India)	Non-Member Asstt. Secretary

Research Advisory Committee
(w.e.f. Feb 13, 2019)

Sl.	Name	Address	Status
1.	Dr. Shailesh Nayak	Director National Institute of Advanced Studies Indian Institute of Science campus, Bengaluru -560012	Chairman
2.	Prof. Talat Ahmad	Vice Chancellor University of Kashmir, Hazratbal, Srinagar Jammu & Kashimir - 190006	Member
3.	Prof. D.C. Srivastava	Department of Earth Sciences Indian Institute of Technology Roorkee, Roorkee - 247667	Member
4.	Prof. O.N. Bhargava	(Ex-Director, GSI) 103, Sector-7, Panchkula - 134109	Member
5.	Dr. K.J. Ramesh	D.G., IMD Mausam Bhavan, Lodi Road, New Delhi - 110 003	Member
6.	Dr. P.P. Chakraborty	Professor, Department of Geology, University of Delhi, Delhi - 110007	Member
7.	Prof. N.V. Chalapathi Rao	Department of Geology, Banaras Hindu University(BHU) Varanasi(U.P.) - 221 005	Member
8.	Dr. Thamban Meloth	Scientist 'F', & Group Director (Polar Sciences) National Centre for Polar and Ocean Research, Ministry of Earth Sciences, Govt. of India, Headland Sada, Vasco-da-Gama, Goa-403 804	Member
9.	Dr. O.P. Mishra	Scientist 'F', Ministry of Earth Sciences, Government of India, Prithvi Bhavan, Opp. India Habitat Centre, Lodhi Road, New Delhi- 110 003	Member
10.	Dr. Prakash Chauhan	Director, Indian Institute of Remote Sensing, 4, Kalidas Road, Dehradun - 248001	Member
11.	Prof. Biswajit Mishra	Geology and Geophysics Indian Institute of Technology, Kharagpur, 721302	Member
12.	Prof. Avinash Chandra Pandey	Director Inter- University Accelerator Centre Aruna Asaf Ali Marg,Near Vasant Kunj, New Delhi - 110067	Member
13.	Prof. Ajoy Bhowmik	Associate Professor Department of Applied Geology Indian Institute of Technology (Indian School of Mines), Dhanbad - 826004, Jharkhand	Member
14.	Dr. Vandana Prasad	Director Birbal Sahni Institute of Paleoscience 53, University Road, Lucknow-226 007	Member
15.	Dr. Prantik Mandal	Chief Scientist, Co-ordinator & Professor at AcSIR-NGRI, Theoretical & Computational Geophysics Group, CSIR-NGRI, Uppal Road, Hydearbad - 500 007, Telangana	Member
16.	Prof. Anil V. Kulkarni	Distinguished Visiting Scientists Divecha Centre for Climate Change, Indian Institute of Science, Bengaluru- 560012, Karnataka	Member

Research Advisory Committee
(w.e.f. Feb 13, 2019)

Sl.	Name	Address	Status
17.	Dr. Kalachand Sain	Director Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
18.	Dr Rajesh Sharma	Scientist 'G' Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary

Finance Committee
(w.e.f. Feb 13, 2019)

Sl.	Name	Address	Status
1.	Sh. B. Anand	Financial Advisor Department of Science & Technology, Technology Bhavan, New Mehrauli Road, New Delhi- 110016	Chairman
2.	Dr. Rasik Ravindra	608, Lalleshwari Apart Sector 21 D, Faridabad- 121 001	Member
3.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
4.	Sh. Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
5.	Mrs. Manju Pant	Assistant Finance & Accounts Officer Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary

Building Committee
(w.e.f. Feb 13, 2019)

Sl.	Name	Address	Status
1.	Dr. Kalachand Sain	Director, Wadia Institute of Himalayan Geology, Dehradun - 248 001	Chairman
2.	Sh. B. Anand or his/her nominee	Financial Advisor Department of Science & Technology Technology Bhavan, New Mehrauli Road, New Delhi - 110016	Member
3.	Dr. H.K. Sachan	Scientist-'G', Wadia Institute of Himalayan Geology, Dehradun 248001	Member
4.	Representative of Survey of India	Hathibarkala, Dehradun	Member
5.	Sh. D. K. Tyagi	General Manager (Civil) Infrastructure Development, Oil & Natural Gas Corporation, Dehradun - 248 001	Member
6.	Sh. Prashant Singh	Executive Engineer, CPWD, 20, Subhash Road, Dehradun - 248 001	Member
7.	Mrs. Poonam Gupta	Sr. Principal Scientist CSIR-Indian Institute of Petroleum, Haridwar Road, Dehradun - 248 005	Member
8.	Sh. Pankaj Kumar	Registrar, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member
9.	Sh. C.B. Sharma	Assistant Engineer, Wadia Institute of Himalayan Geology, Dehradun - 248001	Member Secretary

STATEMENT OF ACCOUNTS

BHATIA SUBHASH & CO.
CHARTERED ACCOUNTANTS
Dehradun Off: *17 Pankaj Vihar, Pitthuwala, Simla By Pass, Po Mehuwala, Dehradun (U.K)*
Sre Off: *IInd Floor, Narayan Tower, Opp. Narayan Mandir, Gill Colony, Saharanpur (U.P)*
Yamunanagar Off: *H.No 1140, Sector 17 Huda, Jagadhri Yamunanagar – 135001 (H.R)*

Tel.No. 9528173229, 9897226991 ***Email: rkgupta091@gmail.com, rkguptarke@yahoo.com***

AUDITOR'S REPORT ON CONSOLIDATED FINANCIAL STATEMENTS

The Members of Governing Body,
Wadia Institute of Himalayan Geology,
33, GMS Road, Dehradun
Uttarakhand

We have audited the accompanying Consolidated Financial Statements of **WADIA INSTITUTE OF HIMALAYAN GEOLOGY, 33, GMS Road, Dehradun** for the year ended March 31st, 2020 which comprises Balance Sheet ,Income and Expenditure Account, Receipt and Payment Account and summary of significant accounting policies.

Society's management is responsible for the preparation of these Financial Statements in accordance with law. This responsibility includes the design, implementation and maintenance of internal control relevant to the preparation and presentation of the financial statements that give a true and fair view and are free from material misstatement, whether due to fraud or error.

Our responsibility is to express an opinion on these financial statements based on our audit. We conducted our audit in accordance with the Standards on Auditing issued by the Institute of Chartered Accountants of India. Those Standards require that we comply with ethical requirements and plan and perform the audit to obtain reasonable assurance about whether the financial statements are free from material misstatement.

An audit involves performing procedures to obtain audit evidence about the amounts and disclosures in the financial statements. The procedures selected depend on the auditor's judgment, including the assessment of the risks of material misstatement of the financial statements, whether due to fraud or error. In making those risk assessments, the auditor considers internal control relevant to the Society's preparation and fair presentation of the financial statements in order to design audit procedures that are appropriate in the circumstances. An audit also includes evaluating the appropriateness of accounting policies used and the reasonableness of the accounting estimates made by management, as well as evaluating the overall presentation of the financial statements.

We believe that the audit evidence we have obtained is sufficient and appropriate to provide a basis for our audit opinion.

Bhatia Subhash & Co. Dehradun Chartered Accountants

AUDITOR'S REPORT

In our opinion and to the best of our information and according to the explanations given to us, the financial statements give the information required by the Act in all material respects and give a true and fair view in conformity with the accounting principles generally accepted in India subject to our comments given in Annexure-"1":

a) in the case of the Balance Sheet, of the state of affairs of the Society as at March 31st, 2020;
b) in the case of the Income and Expenditure Account of the deficit for the year ended on that date; and
c) in the case of the Receipt and Payment Account, of the cash flows for the year ended on that date.

FOR BHATIA SUBHASH & CO
CHARTERED ACCOUNTANTS

CA RAHUL GUPTA
FCA, DISA (ICAI), PARTNER

FRN: 023033N
M.NO: 425249
UDIN : 20425249AAAAGR8172

Date: 18th Sept, 2020
Place: Dehradun

BHATIA SUBHASH & CO.
CHARTERED ACCOUNTANTS
Dehradun Off: 17 Pankaj Vihar,Pitthuwala, Simla By Pass, Po Mehuwala, Dehradun (U.K)
Sre Off: IInd Floor, Narayan Tower, Opp. Narayan Mandir, Gill Colony, Saharanpur (U.P)
Yamunanagar Off: H.No 1140, Sector 17 Huda, Jagadhri Yamunanagar – 135001 (H.R)

Tel.No. 9528173229, 9897226991 *Email: rkgupta091@gmail.com, rkguptarke@yahoo.com*

Annexure-1 to the Consolidated Financial Statement of Audit Report (F.Y. 2019-20)

The following observations were noticed during the course of audit for the Financial Year 2019-20. The same have been discussed with the management and comments/explanations of the management thereon have also been observed.

SI. No.	Comments/Observations by Chartered Accountants
1.	The Institute is maintaining accounts on cash basis except interest accrued on investments, which is not conformity with the generally accepted accounting policy adopted in India and as per the accounting standard-1 "Disclosure of Accounting Policies" issued by the Institute of Chartered Accountants of India. The "Uniform Accounting Format" of financial statements of the central autonomous bodies as has been made compulsory by the Ministry of finance w. e. f. 01.04.2001 and adopted by the Institute also, recommends accrual method of accounting.
2.	The Institute has not booked the current liability for the retirement benefit of the employees as per Accounting Standard-15 "Employee Benefits" as issued by the Institute of Chartered Accountants of India.
3.	The internal control regarding fixed assets needs to be strengthened. The following observation are made: a) The physical verification of fixed assets for the financial year 2018-19 and 2019-20 has not been undertaken. While auditing the accounts in the store section it was observed following Assets Register were maintained by the store section:- **[Details]** A. 1. Assets-1 2. Assets-2 3. Assets-3 4. Assets-4 5. Assets-5 B. General Equipment C. Field Equipment D. Vehicle register E. Engineering Section F. Fixed Assets buildings. Physical verification of the above mentioned Assets have not been carried out by the verifying officer till date. Reason of not doing the needful may be specified.

Bhatia Subhash & Co. Dehradun Chartered Accountants

Physical verification of library not conducted.

While auditing the accounts pertaining to the Library located inside WIHG it was observed that physical verification of the books/journals and magazines available in the library have not been physically verified till the date of completion of audit report. The reason for not complying with the rule laid down in GFR regarding physical verification of Assets may be specified.

4. The contribution towards medical scheme for pensioners is accounted for in pension fund account whereas the payment of actual expenditure is met from the institute account. it is recommended that the expenses should be met from the specific fund only.

5. It was observed that Institute is maintaining its financial accounting in the software developed in FOXPRO Database with clipper compilation which is based on the huge codification process and not has the window base verification system. This software is obsolete in the present scenario comparing with the recent available Accounting software in use. To maintain the accounts of institute it is suggested that a software which is more user friendly to all the staff working in the account section and that to customized as per the need of the institute be developed. The management of the Institute needs to take urgent action.The institute has purchased “Tally Software” for maintaining records of the financial transactions/ledgers etc. The shifting of all records/ledgers to Tally Software is under process.

6. During the audit it was observed that the Mr. Uttam Singh has been suspended in November, 2013 but there is CPF balance of Rs. 34658/- outstanding in the books of institute.

7. It was observed that several projects are appearing in Financial Statements where no transactions has undertaken since long, the management is advised to take appropriate action for final settlement. **Non-maintenance of books of accounts in respect of 58 projects** While auditing the balance sheet of the project it was observed that Balance Sheet for a total number of 141 projects was prepared up to the current financial year. However books of accounts for 58 projects were neither prepared nor maintained by the WIHG. The reason for not maintaining the books of accounts for the above projects may be specified.

8. During the course of audit it was observed that there is outstanding demand of Rs. 56530.00 in traces website the year wise and form wise break is as follows:

F.Y.	Form Type	TDS demand
2007-08	26Q	160.00
2009-10	26Q	120.00
2016-17	26Q	12860.00
2017-18	26Q	20290.00
2018-19	26Q	23100.00
Total		**56530.00**

9. **Non Adjustment of Advances against the staff Debtors:**
Some advances against staff debtors and Party Debtors are pending for recovery since long time. The Party Debtors amounting to Rs.1900024.00 and staff debtors amounting to Rs.2115283.00 .The advance which could not be realized in due course should be written off with the approval of the competent authority. Please clarify, if they are irrecoverable nature, initiative for write off is required.

10. There is a GST TDS which is deducted and deposited by Party to whom service is rendered under Consultancy Project of which credit not taken by institute by filling GST TDS -7 Returns.
Details are as follow:

1. Chenab Valley Power Project	Rs.119000.00
2. CSIR Nantionl Env Jaipur	Rs.360.00
3. Rajasthan Vishwavidhyalya	Rs.1200.00
Total	**Rs.120560.00**

It is a revenue loss for Institute.

Bhatia Subhash & Co. Dehradun Chartered Accountants

11.	**Bank reconciliation** In bank Reconciliation provided to us showing unadjusted entries since Jan 2005. It is suggested to clear/adjusted the same.
12.	As informed by management that CSIR (WI) Project has been closed but a sum of amounts of Rs.156478.00 received in Bank A/c from an unknown sources of which management has not provide the information/explanation of the source of credit.

FOR BHATIA SUBHASH & CO
CHARTERED ACCOUNTANTS

CA RAHUL GUPTA
FCA, DISA (ICAI) PARTNER

FRN: 023033N
M.NO: 425249

Date: 18th Sept, 2020
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

BALANCE SHEET
(AS AT 31ST MARCH 2020)

(Amt in Rs...)

PARTICULARS	SCHEDULE	CURRENT YEAR	PREVIOUS YEAR
LIABILITIES			
Corpus/ Capital Fund	1	69,41,46,273	73,53,40,049
Reserves and Surplus	2		-
Earmaked/ Endowment Fund	3	12,53,319	17,86,224
Secured Loans & Borrowings	4		-
Unsecured Loans & Borrowings	5		-
Deferred Credit Liabilities	6		-
Current Liabilities & Provisions	7	1,28,86,938	1,95,81,291
TOTAL		**70,82,86,530**	**75,67,07,564**
ASSETS			
Fixed Assets	8	34,49,43,451	37,06,15,597
Investments from Earmaked/		-	-
Endowment Funds	9	-	47,115
Investment- Others	10	-	-
Current Assets, Loans & Advances	11	36,33,43,079	38,60,44,852
TOTAL		**70,82,86,530**	**75,67,07,564**
Significant Accounting Policies	37		
Contingent Liabilities and Notes on Accounts	38		

AUDITOR'S REPORT
"As per our separate report of even date"

FOR BHATITA SUBHASH & CO.
CHARTERED ACCOUNTANTS

CA RAHUL GUPTA
(F.C.A, DISA (ICAI))

(RAHUL SHARMA)	**(PANKAJ KUMAR)**	**(DR. KALACHAND SAIN)**
A F & A.O	**Registrar**	**Director**

Date : 18th September, 2020
Place : Dehradun

1

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

INCOME & EXPENDITURE ACCOUNT
FOR THE PERIOD ENDED 31ST MARCH 2020

(Amt in Rs…)

S.NO.	PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
A	**INCOME**			
	Income from sales/ services	12		-
	Grants/ Subsidies	13	37,11,15,482	25,17,62,408
	Fees/Subscription	14	55,153	47,500
	Income from Investments	15	12,63,625	8,69,959
	Income from Royalty, Publication etc.	16	1,25,401	1,13,894
	Interest earned	17	1,43,58,819	2,55,56,417
	Other Income	18	1,20,02,502	84,56,509
	Increase/ Decrease in Stock (Goods & WIP)	19	-	-
	TOTAL (A)		**39,89,20,982**	**28,68,06,687**
B	**EXPENDITURE**			
	Establishment Expenses	20	33,25,58,820	24,05,99,595
	Other Research & Administrative Expenses	21	7,03,25,274	6,55,99,486
	Expenditure on Grant/ Subsidies etc.	22	-	-
	Interest/ Bank Charges	23	81,81,281	82,20,852
	Depreciation Account	8	5,49,12,834	8,92,76,205
	Increase/ Decrease in stock of Finished goods, WIP& Stock of Publication	A-2	(10,308)	22,938
	Loss / (Profit) on sale of Assets	A-19	-	
	TOTAL (B)		**46,59,67,901**	**40,37,19,076**
	Surplus/ (Deficit) being excess of Income over Expenditure (A - B)		(6,70,46,919)	(11,69,12,389)
	Transfer to Special Reserve (Specify each)		-	-
	Transfer to / from General Reserve		-	-
	BALANCE BEING SURPLUS /(DEFICIT)		**(6,70,46,919)**	**(11,69,12,389)**
	CARRIED TO CORPUS FUND		**6,70,46,919**	**11,69,12,389**

AUDITOR'S REPORT

"As per our separate report of even date"

FOR BHATIA SHUBHAS & CO.
CHARTERED ACCOUNTANTS

CA RAHUL GUPTA
(F.C.A. DISA (ICAI))

(RAHUL SHARMA)
A F & A.O

(PANKAJ KUMAR)
Registrar

(DR. KALACHAND SAIN)
Director

Date : 18th September, 2020
Place: Dehradun

AUDITOR'S REPORT

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN

RECEIPTS & PAYMENTS ACCOUNT
(FOR THE YEAR ENDED 31st MARCH 2020)

(Amt in Rs…)

PARTICULARS	SCH.	CURRENT YEAR	PREVIOUS YEAR
RECEIPTS			
Opening Balance	24	22,37,50,227	28,57,01,945
Grants - in - Aids	26	40,85,53,482	26,48,29,408
Grants - in - Aids/Other Receipts (Ear Marked	27	2,09,95,716	2,39,42,213
Loan & Advances	28	25,56,85,961	18,70,68,496
Loan & Advances (Ear Marked)	31	4,00,000	
Fees/Subscription	14	55,153	47,500
Income from Investments	15	12,63,625	8,69,959
Income from Royalty, Publication etc.	16	1,25,401	1,13,894
Interest earned	17	85,28,129	1,77,06,510
Other Income	18	1,20,02,502	84,56,509
Investment (L/C Margin Money)	34	50,00,000	-
		93,63,60,196	**78,87,36,434**
PAYMENTS			
Establishment Expenses	20	33,25,58,820	24,05,99,595
Other Administrative Expenses	21	7,03,25,274	6,55,99,486
Expenditure on Grant/Subsidies Etc.	22	-	-
Interest/ Bank Charges	23	81,81,281	80,39,565
Loans & Advances	29	24,75,06,189	18,77,63,212
Loans & Advances (Ear Marked)	32	8,53,365	-
Investment (L/C Margin Money)	35	-	-
Fixed Assets	36	2,92,40,689	3,96,98,974
Ear Marked Fund Expenses	33	2,17,95,941	2,32,85,376
Grant - in - Aid (Ear Marked) Refunded	30	-	-
Closing Balance	25	22,58,98,636	22,37,50,226
		93,63,60,196	**78,87,36,434**

AUDITOR'S REPORT
"As per our separate report of even date"

FOR BHATIA SUBHASH & CO.
CHARTERED ACCOUNTANTS

CA RAHUL GUPTA
(F.C.A, DISA (ICAI))

(RAHUL SHARMA) A F & A.O — **(PANKAJ KUMAR)** Registrar — **(DR. KALACHAND SAIN)** Director

Date : 18th September, 2020
Place: Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33, GMS ROAD DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31^{ST} MARCH, 2020

SCHEDULE – 37: SIGNIFICANT ACCOUNTING POLICIES

1. ACOUNTING CONVENTION

   The financial statements are prepared on the basis of historical cost convention, unless otherwise stated and on the cash method of accounting except interest accrued on fixed deposit.

2. INVESTMENTS

   Investments classifieds as "long term investments" are carried at cost.

3. FIXED ASSETS

   a) Fixed Assets are stated at net book value as recommended in the "Uniform Accounting Format" of financial statements for the Central Autonomous Bodies as made compulsory by the Ministry of Finance w.e.f. 01.04.2001.
   b) Additions to fixed assets are taken at cost of acquisition, inclusive of freight, duties and taxes, incidental and direct expenses related to acquisition.

4. DEPRECIATION

   a) Depreciation is provided on Written down Value method as per rates specified in the Income Tax Act, 1961.

   b) When an asset is discarded or sold or deleted, the original cost is deducted from the gross block, the W.D.V. is deducted from the W.D.V. block and accumulated depreciation on the asset upto the date of deletion is deducted from accumulated depreciation of the respective block.

   c) In respect of addition to/ deduction from fixed assets during the year, depreciation is considered on full yearly basis.

Bhatia Subhash & Co.
Dehradun
Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33, GMS ROAD DEHRADUN

5. MISCELLANEOUS EXPENDITURE

   Deferred revenue expenditure, if any, will be written off over a period of 5 years from the year it is incurred.

6. ACCOUNTING FOR SALES & SERVICES

   The consultancy services provided by the institute is accounted for on net service basis.

7. GOVERNMENT GRANTS / SUBSIDIES

   a) Government grants of the nature of contribution towards Capital Cost are directly credited to Corpus Fund and Other Revenue cost are transferred to Income & Expenditure account and the surplus or deficit after deducting all the expenses is transferred to Capital / Corpus fund.

   b) Grants towards Earmarked / Endowment Funds are directly transferred to the respective fund account.

   c) Government grants / subsidy are accounted on realization basis.

(Rahul Sharma)	**(Pankaj Kumar)**	**(Dr. Kalachand Sain)**
A.F. & A.O	**Registrar**	**Director**

Date : 18th September, 2020
Place: Dehradun

Bhatia Subhash & Co.
Dehradun
Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

SCHEDULE FORMING PART OF ACCOUNTS FOR THE YEAR ENDED 31ST MARCH, 2020

SCHEDULE – 38: CONTINGENT LIABILITIES AND NOTES ON ACCOUNTS

1. CONTINGENT LIABILITIES

(Amount in Rs.)

a)	Claims against the Entity not acknowledged as debts		- Nil -
b)	In respect of		
	i)	Bank Guarantees given by /on behalf of the Entity	- Nil -
	ii)	Letter of credit opened by Bank on behalf of the entity	-Nil-
	iii)	Bills discounted with banks	- Nil -
c)	Disputed demands in respect of		
	i)	Income –tax (TDS)	56530.00
	ii)	Sales tax	- Nil -
	iii)	Municipal Taxes	- Nil -
d)	In respect of claims from parties for non-execution of orders, but contested by the Entity		- Nil -

2. CAPITAL COMMITMENTS

Estimated Value of contracts remaining to be executed on capital account and not provided for (net of advances)		
a)	Construction of Building	- Nil -
b)	Other Assets	-Nil -

3. LEASE OBLIGATIONS

Future obligations for rentals under finance lease arrangements for plant and machinery amount to Rs. Nil	- Nil -

4. CURRENTS ASSETS, LOANS AND ADVANCES

In the opinion of the Institute, the current assets, loans and advances have a value on realization in the ordinary course of business, equal at least to the aggregate amount shown in the Balance Sheet.

5. TAXATION

In view of there being no taxable income of the Institute under income tax Act, 1961, no provision for Income Tax has been considered necessary

Bhatia Subhash & Co. Dehradun Chartered Accountants

WADIA INSTITUTE OF HIMALAYAN GEOLOGY,
33 GMS ROAD, DEHRADUN

6. FOREIGN CURRENCY TRANSACTIONS

a)	Value of Imports Calculated on C.I.F basis:		
	i)	Purchase of finished goods	- Nil -
	ii)	Raw Materials & Components (including in transit)	- Nil -
	iii)	Capital goods	- Nil -
	iv)	Stores, Spares and Consumables	- Nil -
b)	Expenditure in foreign currency		
	i)	Travel (for attending Seminar/Conference abroad)	- Nil -
	ii)	Remittances and Interest payment to Financial Institutions / Banks in Foreign Currency	- Nil -
	iii)	Other expenditure	
		Commission on Sales	- Nil -
		Legal and Professional Expenses	- Nil -
		Miscellaneous Expenses	- Nil -
c)	Earnings		
	i)	Value of Exports on FOB basis	- Nil -
	ii)	Grants for Projects	- Nil -

7. The payments to auditors during the F.Y. 2019 -20 is as follows:

Remuneration to auditors		
i)	As Auditors	47,200/-
	Taxation matters	- Nil -
	For Management Services	- Nil -
	For Certification	- Nil -
ii)	Others	- Nil -

8. Separate Financial Statements have been prepared for:

a) Wadia Institute of Himalayan Geology.
b) Contributory/ General Provident Fund.
c) Pension Fund.
d) Consolidated financial statement of projects sponsored by other Agencies.
e) Individual financial statements of Projects sponsored by other agencies.

9. Corresponding figures for the previous year have been regrouped / rearranged, wherever necessary.

10. Annexed Schedules & Annexures are an integral part of the Balance Sheet as on 31st March, 2020, Income and Expenditure Account and Receipt & Payment for the year ended on 31st March, 2020.

(Rahul Sharma) 18/9/20
A.F. & A.O

(Pankaj Kumar) 18/9
Registrar

(Dr. Kalachand Sain) 18/9/20
Director

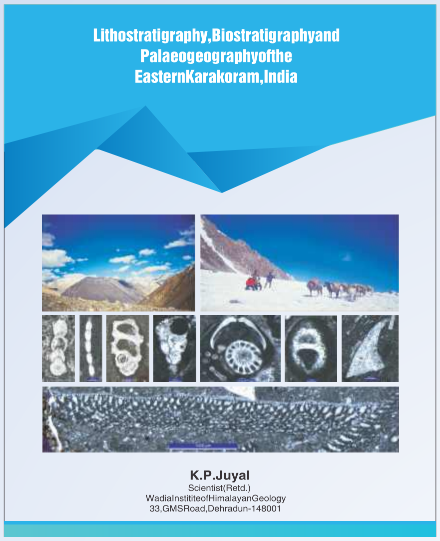
Date : 18th September, 2020
Place: Dehradun

Bhatia Subhash & Co. Chartered Accountants Dehradun

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRADUN

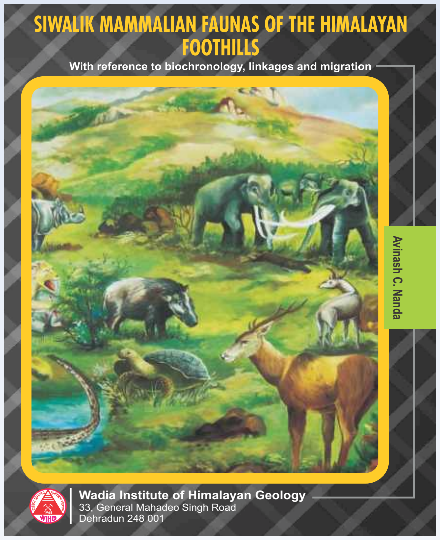
Latest Publications

2018

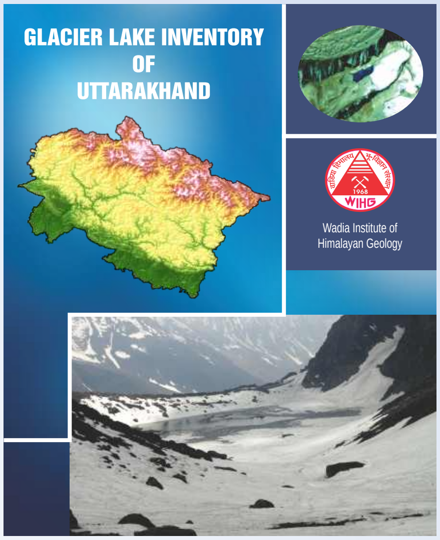


Rs.600/- (India), US$ 50/- (Abroad)

2015

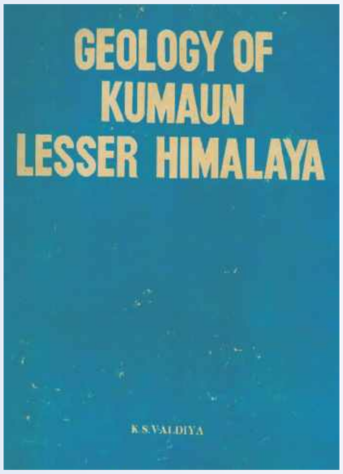


Rs.1200/- (India), US$ 100/- (Abroad)

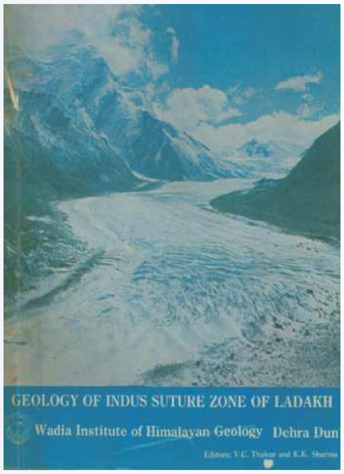


Price: Rs. 500/- (India), US$ 50/- (Abroad)

Previous Publications



Rs.180/- (India), US$ 50/- (Abroad)



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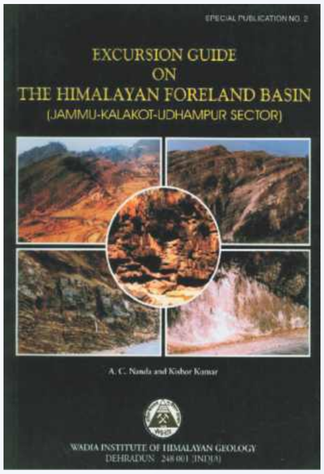

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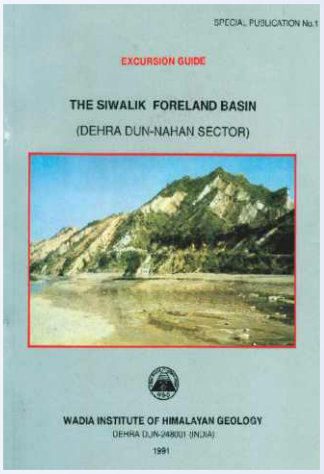

Rs.45/- (India), US$ 8/- (Abroad)

Rs.200/- (India), US$ 15/- (Abroad)

Procurement details:
Corresponding address:
The Director
Wadia Institute of Himalayan Geology,
33, GMS Road, Dehradun 248001, India
or
Asstt. Publication & Doc. Officer
Wadia Institute of Himalayan Geology,
33, GMS Road, Dehradun 248001, India
Phone: +91-0135-2525430, Fax: 0135-2625212
Email: himgeol@wihg.res.in,
Web: http://www.himgeology.com

Cheque/Bank Draft:
Should be in favour of the
'Director, WIHG, Dehradun, India'

WADIA INSTITUTE OF HIMALAYAN GEOLOGY, DEHRA DUN
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(These volumes are the Proceedings of the Annual Seminars on Himalayan Geology organizsed by the Institute)

		(in Rs)	(in US $)
Volume 1	(1971)	130.00	26.00
Volume 2*	(1972)	50.00	
Volume 3*	(1973)	70.00	
Volume 4*	(1974)	115.00	50.00
Volume 5	(1975)	90.00	50.00
Volume 6	(1976)	110.00	50.00
Volume 7	(1977)	110.00	50.00
Volume 8(1)	(1978)	180.00	50.00
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Volume 9(1)	(1979)	125.00	35.00
Volume 9(2)	(1979)	140.00	45.00
Volume 10	(1980)	160.00	35.00
Volume 11	(1981)	300.00	60.00
Volume 12	(1982)	235.00	47.00
Volume 13*	(1989)	1000.00	100.00
Volume 14* (in Hindi)	(1993)	600.00	-
Volume 15*	(1994)	750.00	

(Available from M/s Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, Bombay, Kolkata)

Volume 16*	(1999)	1000.00	100.00

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(A bi-annual Journal : published from 1990 to 1995)

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Institutional	500.00	50.00
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Volume 1 (1990) to Volume 6 (1995)*

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HIMALAYAN GEOLOGY

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Volume 18 (1997) to Volume 26 (2005)*
Volume 27 (2006) to Volume 30 (2009)
Volume 31 (2010) to Volume 32 (2011)*
Volume 33 (2012)
Volume 34 (2013) to Volume 36 (2016)*
Volume 37 (2015) to Volume 38 (2017)
Volume 39 (2018)

Revised Annual Subscription (w.e.f. 2018):	(in Rs)	(in US$)
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Individual (incl. postage)	600.00	50.00
Individual (excl. postage)	500.00	

Volume 40(2019) to Volume 41(2020)

OTHER PUBLICATIONS

Geology of Kumaun Lesser Himalaya, 1980 (by K.S. Valdiya)	Rs. 180.00 US $ 50.00
Geology of Indus Suture Zone of Ladakh, 1983 (by V.C.Thakur & K.K. Sharma)	Rs. 205.00 US $ 40.00
Bibliography on Himalayan Geology, 1975-85	Rs. 100.00 US $ 30.00
Geological Map of Western Himalaya, 1992 (by V.C. Thakur & B.S. Rawat)	Rs. 200.00 US $ 15.00
Excursion Guide :The Siwalik Foreland Basin (Dehra Dun-Nahan Sector), (WIHG Spl. Publ. 1,1991) (by Rohtash Kumar and Others)	Rs. 45.00 US $ 8.00
Excursion Guide : The Himalayan Foreland Basin (Jammu -Kalakot-Udhampur Sector) (WIHG Spl Publ. 2, 1999) (by A.C. Nanda & Kishor Kumar)	Rs. 180.00 US $ 15.00
Glacier Lake Inventory of Uttarakhand (by Rakesh Bhambri et al. 2015)	Rs. 500.00 US $ 50.00
Siwalik Mammalian Faunas of the Himalayan Foothills With reference to biochronology, linkages and migration (by Avinash C. Nanda, 2015)	Rs. 1200.00 US $ 100.00
Lithostratigraphy, Biostratigraphy and Palaeogeography of the Eastern Karakoram, India (by K.P. Juyal, 2018)	Rs. 600.00 US $ 50.00

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33, General Mahadeo Singh Road, Dehradun-248001 (INDIA)